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SOIL and CROP SCIENCE SOCIETY of FLORIDA

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1996

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FIFTY-FIFTH ANNUAL MEETING
HOLIDAY INN SUNSPREE RESORT AND CONFERENCE CENTER
DAYTONA BEACH, FLORIDA
20-22 SEPTEMBER 1995

Logo of the Soil and Crop Science Society of Florida. At the 40th Annual Business Meeting at 1120 h, 8 Oct. 1980 at the Holiday Inn, Longboat Key, Sarasota, FL, a report was presented by the *ad hoc* Logo Committee composed of J. J. Street, Chair, R. S. Kalmbacher, and K. H. Quesenberry. All Society members were eligible to participate in the contest which would result in the selection of a logo design for the SCSSF. The presentation of the winning entry would be made at the 1981 Annual Meeting. David H. Hubbell was announced as the winner of the contest and was awarded a free 10-yr membership in the Society. The design, shown above, depicted the chief interests of the Society: Florida Soils, and Crops. Soils and Crops were given equal weight with Florida. Soils was depicted as the soil texture triangle which shows the percentage of sand, silt, and clay in each of the textural classes, but simplified so as to permit clarity in reduction when printed. Crops was shown as a stylized broadleaf plant, including the roots. Florida was shown, minus its keys, with only one physical feature in its interior, Lake Okeechobee. Enclosed within nine rays such as might be envisioned as being made by the sun emitting light (sunburst) behind the symbols are two concentric circles containing the words "SOIL AND CROP SCIENCE SOCIETY" in the top semicircle and "FLORIDA" at the bottom of the lower semicircle. A schematic likeness of the State of Florida occupies 0.5 of the area within the smaller circle, while the symbol for Soils and the symbol for Crops occupy 0.25 of the area each, with the sum of the three parts totalling unity.

The first printing of Society stationery following the award on 28 Oct. 1981, and the printed program of the Society since the 1982 meetings, have featured the logo.

V. E. Green, Jr., Editor, Volume 45

Published annually by the Soil and Crop Science Society of Florida. Membership dues including subscription to annual Proceedings are $20.00 per year for domestic members and $22.00 per year for foreign members. At least one author of a paper submitted for publication in the Proceedings must be an active or honorary member of the Society except for invitational papers. Ordinarily, contributions shall have been presented at annual meetings; exceptions must have approval of the Executive Committee and the Editorial Board. Contributions may be (1) papers on original research or (2) invitational papers of a philosophical or review nature presented before general assemblies or in symposia. A charge of $30.00 per printed page in the Proceedings will be billed to the agency the author represents to help defray printing costs. Members are limited to senior authorship of one volunteer paper per volume; there is no limit for junior authorships.

SOIL AND CROP SCIENCE SOCIETY OF FLORIDA

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SOCIETY AFFAIRS

DEDICATION OF THE FIFTY-FIFTH PROCEEDINGS SOIL AND CROP SCIENCE SOCIETY OF FLORIDA
Dr. Kuell Hinson

DR. KUELL HINSON

Dr. Kuell Hinson was a soybean breeder of world renown from the USDA-ARS and the Univ. of Florida.

Dr. Hinson was born 8 Jan. 1924 at Moss, TN, and grew up in that area of north central Tennessee. After serving in the Army Air Force during WWII, he attended Tennessee Technological Univ., where he earned his B.S. degree in agriculture in 1949. He earned his M.S. and Ph.D. degrees from the University of Wisconsin in 1951 and 1954, respectively, under the direction of W. K. Smith.

In 1954, Dr. Hinson was employed by USDA-ARS for soybean breeding and genetics research at the Univ. of Florida in Gainesville. He received courtesy appointments to the Univ. of Florida faculty in the three professional ranks, directed graduate programs of 25 candidates for advanced degrees, lectured on topics related to soybean, and served on various student and departmental committees.

Dr. Hinson pioneered the development of soybean cultivars well-adapted to the coastal plain soils of the southeastern USA, with the release of 'Hardee' and 'Bragg' in 1962 and 1963. By the 1970s, Bragg occupied about 50% of the southern U.S. soybean acreage, 10% of the total U.S. acreage, and was widely grown in low latitude temperate regions of Asia and South America. In 1972, he released 'Jupiter', which initiated production in many tropical areas around the globe, especially in South America and Mexico. As nematode and other pest problems increased on soybeans in the southeastern USA, Dr. Hinson incorporated new and multiple sources of pest resistance into high-yielding genotypes. His 12 cultivar releases include types in which resistance to two major races of soybean cyst nematode, three species of root-knot nematode, and important bacterial and fungal diseases are combined in one genotype. Dr. Hinson's successful breeding program contributed to pedigrees of public and commercial soybean cultivars in the USA and abroad.

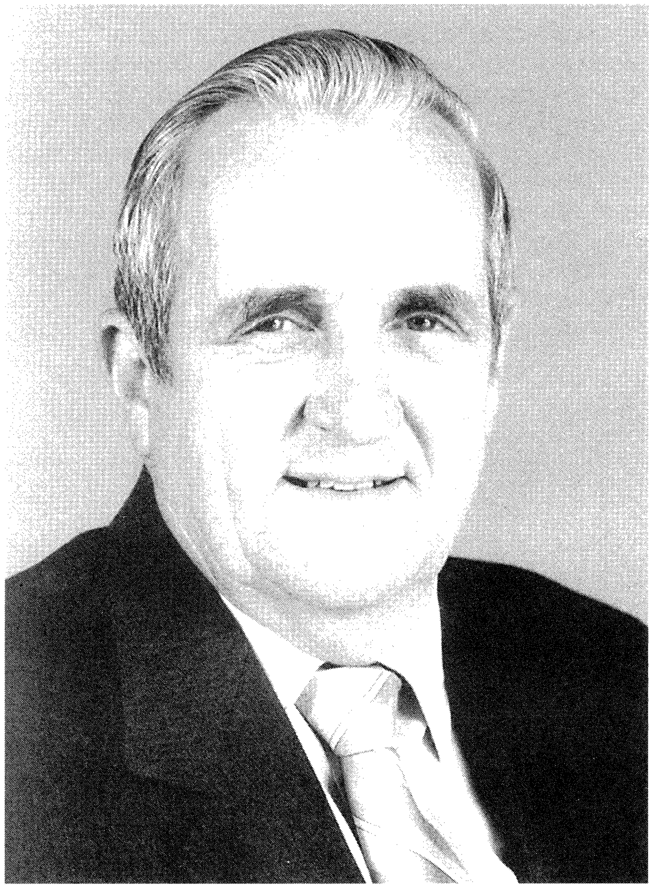
Dr. Hinson served as president of the Soil and Crop Science Society of Florida (1977), was Associate Editor of the *Agronomy Journal* (1979-1981), reviewed numerous manuscripts, and served on other national committees and work groups. In 1979, he was a member of a seven-person ARS-SAES team representing diverse crop species, which carried out a 30-day mission to the People's Republic of China to arrange germplasm exchange. He frequently consulted with foreign visitors to the Univ. of Florida who were interested in soybean research and production, shared germplasm with many, and often accepted invitations for later on-site consultations.

He was recognized for his outstanding contribution to world soybean research at the World Soybean Research Conference IV in Buenos Aires, Argentina, during 1989. Other awards include the American Soybean Association Research Award (1985), the Univ. of Florida Gamma Sigma Delta Senior Faculty Award of Merit (1990), and the Award of Merit (1994) for meritorious service to his profession, the soybean industry, and mankind from the Florida Soybean Growers' Association, the Florida Foundation Seed Producers, the Florida Dep. of Agriculture and Consumer Services, and the Florida Farm Bureau Federation. He was a Fellow of ASA and CSSA.

Dr. Hinson retired from USDA-ARS on 1 Jan. 1993, but continued work on a part-time Univ. of Florida appointment to further explore potentials for the long-juvenile trait in soybean production at low latitudes.

In recognition of his contributions to science, to Florida's agricultural industry, to world agriculture, and to the Soil and Crop Science of Florida, the members of this Society take great pleasure in dedicating Volume 55 of the Proceedings of the Soil and Crop Science Society of Florida to Dr. Kuell Hinson.

HONORARY LIFE MEMBER
Dr. Donald F. Rothwell



DR. RONALD F. ROTHWELL

Dr. Donald F. Rothwell retired from the Soil and Water Science Dep. at the Univ. of Florida on 28 Feb. 1990, following more than 41 years of service. Don was born 21 Oct. 1920 in Brandon, FL, and worked for the Florida Grower Press, and for Seaboard Atlantic Railroad, for 3 years following graduation from high school. He then served for 3 years in the United States Army Air Force prior to entering the Univ. of Florida, from which he received his B.S. and M.S. degrees in Soils in 1948 and 1951, respectively. His Ph.D. degree was received from Purdue Univ. in Agronomy (Soils) during 1955, under the direction of Dr. Lloyd R. Frederick.

During his career, Dr. Rothwell conducted research into soil liming, crop-residue decomposition, symbiotic nitrogen fixation, influence of irradiation on the decomposition of plant materials, pesticide degradation in soils, and solid waste management. In 1960, he was granted one of only three national ORINS Research Fellowships to the UT-AEC Agricultural Research Laboratory in Oak Ridge, TN. For several years, he was leader of a state research project on pesticide degradation in soils, and served as Florida's representative to Southern Technical Committee Regional Project S-62, dealing with inactivation and loss of pesticides from soil.

Over the years from 1948 until his retirement, Don always maintained a heavy teaching load in the Soil Science Dep., teaching approximately 8,000 students in a variety of courses. For several years he served as part of the instructional team for SOS 3022L General Soils and, during the 1980's, as its predominant (and generally sole) instructor. His "trademark" was his reputation as a concerned and caring faculty member, along with his sustained maintenance of the autotutorial General Soils teaching lab. Notable among his other instructional assignments have been courses in Soil Fertility, in Commercial Fertilizers, in Soil Microbiology, and in Advanced Soil Microbiology. He also served for 30 years as a faculty advisor to the Agronomy and Soils Club; and at various times as faculty advisor to the Fraternity of Alpha Zeta, Alpha Gamma Rho fraternity, and the Collegiate Civitan Clubs. He served for 10 years as the departmental Graduate Student Coordinator, for 20 years as the Undergraduate Counselor for the Soil Science Dep., and as a member of the Board of Directors for the Univ. of Florida/Alachua County Alumni Club. He served on multitudinous departmental and University committees, including long-term assignments to the University Senate; the oversight committee for the University's ROTC programs; the University's Tuition Exchange Committee; the College of Agriculture's Honors and Awards, and Undergraduate Curriculum, committees; and as a long-term College, and eventually University, Commencement Marshall.

Don has also been an active participant for more than 40 years with the First United Methodist Church of Gainesville, including long-term service on the church's Administrative Board and on its Board of Trustees. Community service has included long-term involvement with Civitan International, including a term as Governor of the organization's Florida District; and service on the Alachua County Conservation and Recreation Areas Task Force, and to the county's Recreational Funding Task Force.

Dr. Rothwell has been recognized by his fellow workers by being elected Treasurer of the Florida Chapter of Gamma Sigma Delta Honor Society; Treasurer and eventually President of the Florida Chapter of the Society of the Sigma Xi; Secretary-Treasurer and eventually President of the Soil and Crop Science Society of Florida; and Assistant Chairman of the Soil Science Dep.

Don married the former Virginia S. Henderson on June 7, 1947. They have two sons, Fred and Gary, and two grandchildren. In retirement, Don has been enjoying golf, gardening, and continued service in a number of civic and volunteer roles.

SOIL AND WATER SECTION

Potato Cyst Nematodes, a Potential Menace to the Potato Industry of Florida

R. N. Inserra*, R. McSorley, N. Greco, and D. P. Weingartner

ABSTRACT

Environmental conditions of selected Mediterranean and Chilean sites, where potato cyst nematodes (*Globodera rostochiensis* and *G. pallida*) are established as damaging pests of short-cycle potato crops, were compared with those of potato-growing areas in Florida. Potato cyst nematode biological data from these locations were used as parameters to predict the capability of potato cyst nematodes to become established in Florida. The 90-120 d winter-spring potato cycle at the Mediterranean and Chilean sites is similar to that of Florida. Mean soil temperatures during the winter-spring potato-growing season are between the lower and upper threshold limits (10°C or 50°F and 28°C or 82°F, respectively) for potato cyst nematode development and reproduction in the Mediterranean and Chilean locations, as are typical temperatures in Florida. During the potato-growing season, soil temperatures in NE and SE Florida are below the upper temperature limit (28°C or 82°F). Except for short periods late in the crop cycle, temperature would not limit the normal development and maturation of cysts in Florida. Degree days (DD) accumulated during the winter-spring potato-growing season in NE and SE Florida exceed the 400 DD required by cyst nematodes to reach the cyst stage after penetration of second-stage juveniles into the roots. These comparisons suggest that both cyst nematode species, *G. rostochiensis* and *G. pallida*, could develop and reproduce on potato crops during most of the potato-growing seasons (December - April) in both NE and SE Florida. The potato cycles in the warmest months of Florida (June-September) would allow little or no nematode reproduction, but potato production during these months is negligible in the state, because it is not profitable for the growers. Use of seed potatoes from areas free of potato cyst nematodes is essential for keeping these pests out of Florida.

Potato cyst nematodes [*Globodera rostochiensis* (Wollenweber) Behrens and *G. pallida* (Stone) Behrens] are important and widespread pests of potato (*Solanum tuberosum* L.). They became established in the Andean potato-growing areas of South America after migrating from Mexico, their center of origin, and have been spread worldwide on infected potato tubers (Ferris et al., 1995). Except for Australia, Japan, Mexico, the Philippines, Africa, and the United States where only *G. rostochiensis* has been found, these two *Globodera* species have been reported from South, Central, and North America, Europe, the Mediterranean basin, India, New Zealand and the former Soviet Union (Matos and Canto-Saenz, 1993). In the United States, *G. rostochiensis* occurs only in New York state. Effective regulatory programs implemented by the United States Dep. of Agriculture, the Florida Dep. of Agriculture and Consumer Serv., and the use of potato seeds from areas free of potato cyst nematodes (Maine, Minnesota, North Dakota, and Canada are the major seed sources for Florida) have prevented the spread of these pests into other potato-producing regions of the country. Florida is presently free of these two cyst nematodes and, because potatoes in Florida are grown under warm climate conditions which supposedly are unfavorable for cyst nematode infection and development, it has been considered less prone to their establishment than other states. In the past, most studies of the biology and damaging effects of *G. rostochiensis* and *G. pallida* were conducted in temperate and cool regions, especially in northern Europe (Germany, the Netherlands, and the United Kingdom), where these nematodes severely damage potato crops. During the past 15 years, information has become available on the biology and damaging effects of these nematodes on short-cycle (90-100 d) potato crops grown in subtropical environments. Yield losses of 10% (≈$10 million annually) are reported on short-cycle potato crops grown during the winter-spring season in southern Italy (Greco et al., 1993). This information concerning nematode biology and damage to potato under subtropical conditions suggests that *Globodera* spp. could become established in Florida on short-cycle potato crops, and that their accidental introduction would pose risk to the Florida potato industry. The objective of this paper is to compare Florida's environmental conditions, potato cycles, and growing seasons with those of selected subtropical areas in the Mediterranean region and South America, where potato cyst nematodes are established and suppress yield of short-cycle potato crops.

MATERIALS AND METHODS

Three sites were selected in the Mediterranean basin [Cyprus (Philis, 1980), SE Italy (Bari), and Sicily (Catania) (Greco et al., 1988)], one in South America [Chile (La Serena) (Greco and Moreno, 1992a and b)], and two sites in NE and SE Florida (Hastings and Homestead, respectively) (Weingartner et al., 1993; Weingartner and McSorley, 1994). These sites were similar with respect to length of the potato cycle (100 d), growing season (December - May, or September - December for Chile), and soil temperatures (10-25°C or 50-77°F). Soil

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Table 1. Soil characteristics for selected potato-growing areas of the Mediterranean basin, Central Chile, and Florida.†

Soil Components	Cyprus	SE Italy	Sicily	Central Chile	NE Florida	SE Florida
Soil type	Clay soil	Sandy loam soil	Sandy soil	Sandy loam soil	Sandy soil	Perrine marl soil
Sand (%)	20-25	49	80	46	90-95	30-32
Clay (%)	60-65	32.6	6	35	<2.5	34-36
Silt (%)	15-20	16	12	19	<5	32-34
OM (%)	—	2.4	2	—	<2	<2
pH	—	7.5-8	6-7	7-8	5.2-7.0	7-8

†Soil characteristics reported by Philis, 1980; Greco et al., 1988; Greco and Moreno, 1992b; and Weingartner et al., 1993.

and air temperature records for the last 20 yr (1975-1995) were available for the NE Florida site and for 1993-1994 for the SE Florida site. Potato crops are usually irrigated at all sites under comparison. Nematode biological data from the Mediterranean and Chilean sites were used as parameters to predict the capability of cyst nematodes to become established in Florida. For *G. rostochiensis* and *G. pallida* populations worldwide, we assumed a lower threshold temperature of 10°C (50°F) and an upper threshold temperature of 28°C (82°F) for nematode infection and development (Mugniery, 1978; Philis, 1980). These threshold temperatures were used as limits for calculation (Duncan and McSorley, 1987) of degree days (DD) accumulated within this range each month.

No attempt was made to predict potential crop loss due to cyst nematodes in Florida, because crop losses are a function of nematode soil population densities at planting, which cannot be predicted.

RESULTS AND DISCUSSION

The soil physical characteristics of the Mediterranean, Chile and Florida potato-growing areas under comparison are shown in Table 1. Potato soils in NE Florida are as rich in sand (≥ 90%) as are those of Sicily, whereas those of SE Florida are of fine texture (≥ 40% of clay plus silt) and have relatively high pH (7-8) as in SE Italy and Chile. Length of the potato cycle for winter-spring potato crops is 90-120 d for all sites considered (Table 2).

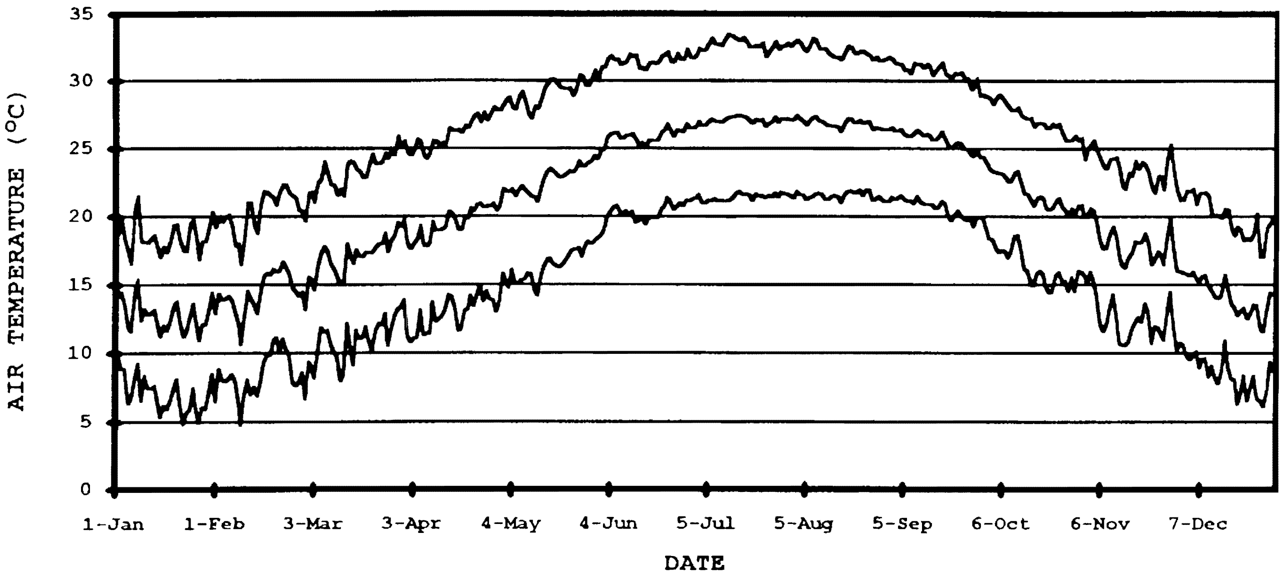
Soil temperatures from plant emergence until harvest during the winter-spring potato-growing season in the Mediterranean and Chilean localities are usually within the upper and lower temperature limits for nematode infection and development. Although soil temperatures in SE and NE Florida can exceed the upper temperature limit for late-season potatoes harvested in April and May, respectively, temperatures during December through March are within the temperature range for development of *G. rostochiensis* (Fig. 1 and Tables 2-4). *Globodera rostochiensis* at the Mediterranean and Chilean sites completes the life cycle in 29-45 d (Philis, 1980; Greco et al., 1988; Greco and Moreno, 1992b). The three-mo period of favorable temperatures in Florida, therefore, would allow for at least one nematode generation and formation of cysts. Cysts, however, could be of a smaller size than those in Mediterranean and Chilean areas due to the higher temperatures (29-32°C) occurring some years at the end of the cycle. Furthermore, even though the upper temperature threshold may be attained on many days late in the Florida potato-growing season (Tables 3, 4), daily mean soil temperatures for this period are almost always within the temperature range for reproduction of *G. rostochiensis* (Fig. 1). Thus, normal development and maturation of cysts could proceed for the entire growing season.

These considerations are also valid for *G. pallida*, which is adapted to cooler temperatures than *G. rostochiensis* (Mungniery, 1978). Soil temperatures during the warmest mo. of June-September exceed the upper limits for cyst nematode reproduction and this factor, coupled with lack of suitable host plants, precludes reproduction of the nematode during the summer mo. in Florida. However, since soil temperatures at the 15 cm soil depth average only ca. 30°C or 86°F even during the warmest months and maximum soil temperature never exceeds 35°C or 95°F (Fig. 1), survival of potato cyst nematodes during this period is likely, even if reproduction is not. Increases in numbers of *G. rostochiensis* up to 39 and 65 times the initial densities are reported in Chile (Greco and Moreno, 1992a) and in southern Italy (Greco et al., 1982), respectively, whereas lower reproductive rates were observed at 15 d exposure to *G. ros-*

Table 2. Potato crop cycles and soil temperatures for selected potato-growing areas of the Mediterranean basin, Central Chile, and Florida.†

Potato growing region	Potato growing seasons (d)	Soil temperature [C° and (F°)]
Cyprus	Jan. - May (120)	13 - 23 (55 - 73)
SE Italy	Feb. - May (100 - 110)	10 - 28 (50 - 83)
Sicily	Dec. - May (109)	8 - 23 (46 - 73)
Central Chile	Sept. - Dec. (90)	15 - 25 (59 - 77)
NE Florida	Dec. - Apr. (105)	11 - 26 (52 - 79)
	Mar. - Jun. (90)	13 - 32 (55 - 90)
SE Florida	Dec. - Apr. (100)	14 - 29 (58 - 84)‡

†Data obtained from Philis, 1980; Greco et al., 1988; Greco and Moreno, 1992b; and Weingartner and McSorley, 1994.
‡Air temperatures.



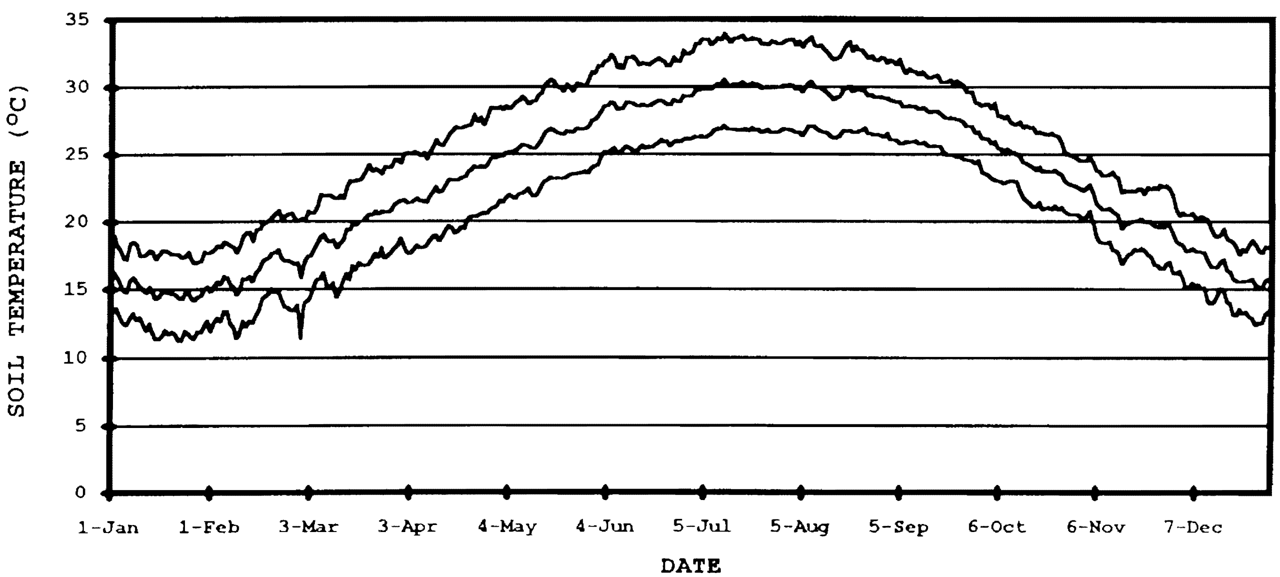


Fig. 1. Air and soil (15 cm depth) temperatures recorded daily during the past 20 yr (1975-1995) at the weather station in Hastings, FL. In each graph the top, middle and bottom lines indicate maximum, average, and minimum temperatures, respectively.

tochiensis cysts (Meredith, 1976) in Venezuela on potato and eggplant (*Solanum melongena* L.) maintained at a mean temperature of 26.8°C. It is worthy to mention that in central Chile, where potato crops are grown all year around, potato cyst nematode reproduction rate varies greatly with planting date. It is greater on potato crops planted in early spring (September - October, 39 × the population level at planting), but it is in turn much lower on potato crops planted in summer (February, 8 ×) or in early winter (June, 8.9 ×) due to the adverse effects of high temperatures during the latter two potato-growing seasons (Greco and Moreno, 1992a). Studies conducted in the Mediterranean areas have shown that *G. rostochiensis* requires 100 and 300-400 DD above the lower threshold temperature for nematode development to reach the adult and cyst stage, respectively, after root penetration by the second-stage juveniles (J2) (Philis, 1980; Greco et al., 1988; Greco and Moreno, 1992a). Furthermore, the majority of J2 in the soil penetrate potato roots during the first three-four wks after potato emergence from soil. Sufficient DD accumulation occurs in both SE and NE Florida during any three-mo period within the winter-spring growing season (Tables 3 and 4) to allow a large proportion of J2s to attain the cyst stage and thereby increase population levels in the soil.

These considerations suggest that *G. rostochiensis* and possibly *G. pallida* could reproduce on a potato

Table 3. Temperature data and accumulated degree d per mo., and d per mo. exceeding the upper temperature limit for development of *Globodera* spp., during the winter-spring potato-growing season in NE Florida during the past 20 yr (1975-1995) and in 1993-1994†.

Month	Mean soil temperature C° and (F°)		Degree d per mo‡		Days with temperatures > 28°C (82°F)			
	20-yr mean	1993-1994	20-yr mean	1993-1994	20-yr mean		1993-1994	
					Air	Soil	Air	Soil
December	16.7 (62.0)	15.8 (60.4)	207	179	0	0	0	0
January	15.0 (59.0)	15.2 (59.3)	156	163	0	0	0	0
February	16.3 (61.3)	18.2 (64.7)	178	229	0	0	2	0
March	19.5 (67.1)	20.7 (69.2)	295	331	0	0	4	0
April	22.9 (73.2)	24.1 (75.3)	386	423	0	0	14	14
May	23.5 (74.3)	23.0 (73.4)	418	403	23	27	26	29

†Temperature data recorded at Univ. of Florida, IFAS, Hastings REC, Hastings, FL. Air temperature recorded in a standard shelter and soil temperature at a depth of 15 cm.

‡Degree d are the sums of daily temperature values ≥ 10°C and ≤ 28°C.

Table 4. Temperature data and accumulated degree d per mo. potentially available for the development of potato cyst nematodes during the winter-spring potato-growing season in SE Florida during 1993-1994.†

Month	Mean temperature [C° and (F°)]		Degree d‡		Days with maximum temperature > 28°C (82°F)	
	Air	Soil	Air	Soil	Air	Soil
November	23 (73)	20 (67)	387	288	21	0
December	19 (66)	16 (61)	270	194	3	0
January	19 (67)	16 (60)	285	175	3	0
February	21 (70)	18 (64)	322	220	10	0
March	21 (70)	19 (67)	350	289	12	0
April	24 (75)	22 (71)	405	348	24	0

†Temperature data recorded from the weather station at Perrine, FL during Nov. and Dec. 1993 and Jan. to April 1994 (National Oceanic and Atmospheric Administration, 1993; 1994).

‡Degree d between 10-28°C (50-82°F) accumulated each month.

crop during most of the typical potato-growing seasons in both NE and SE Florida. Since precise nematode population levels in soil cannot be predicted, it is therefore difficult to estimate the damage that these cyst nematodes would cause to potato production in Florida. Even assuming low (for Florida) nematode reproduction rates of 8 to 10 times the initial densities, soil population levels would increase over time if the current short-term crop rotation regime (six mo. for a winter-spring potato crop followed by six mo. for a cover crop such as sorghum × sudan grass) was not replaced with 3-5-yr long-term rotations with non-host crops. This change in potato crop management to contain nematode reproduction would have serious adverse economic effects for the prosperous potato-growing areas of NE and SE Florida.

Even if production losses due to accidental introduction of these nematodes were minimized with crop rotation, chemical control, and other management practices, heavy financial losses could result from restrictions placed on shipment of Florida potato crops due to quarantines against cyst nematodes in national and international markets. Strict regulation of cyst nematodes is necessary because large areas can be infested by cysts before field symptoms are detectable. In recently infested regions outside of North America, damage in the field has not been detected for up to 10 yr after initial introduction (Seinhorst, unpublished). Meanwhile, cysts were widely distributed on contaminated machinery and on infected tubers.

Information presented in this paper strongly supports the conclusion that it has been the lack of introduction of *Globodera* spp. into Florida, rather than unfavorable environmental conditions for nematode survival and reproduction, which accounts for current absence of these nematodes in the state. Additionally, the study documents the importance of the strict quarantine and regulatory program administered by the United States Dep. of Agric. and the state of New York in preventing the spread of the potato cyst nematodes from New York state or other infested sites to other potato-growing areas of the United States including Florida. Thus, use of seed potatoes from areas free of potato cyst nematodes is essential for the success of these programs and for keeping these pests out of Florida. Efforts made by the United States Dep. of Agric. and by the Florida Dep. of Agric. and Consumer Serv. in containing these nematode pests should be encouraged and supported by Florida potato growers and by growers in other potato-producing growing areas of the country.

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Occurrence of the Citrus Nematode in Old Citrus Growing Regions of Florida

J. J. Ferguson*, L. W. Duncan, and D. E. Norden

ABSTRACT

Citrus nematodes (*Tylenchulus semipenetrans*) were found in 45 of 50 mature citrus groves during a survey conducted in five central, eastern coastal and southwest Florida counties. From a total of 1000 samples the citrus nematode was detected in 475 and 548 soil and root samples, respectively. Approximately half of the infested groves contained trees beneath which no citrus nematodes were found. Many infested groves contained a patchy distribution of infested trees, possibly from random inoculation events. Linear correlations existed between citrus nematode population densities and levels of soil K, Cu, and soluble salts in the Flatwoods counties. In the Central Ridge counties, nematode density was correlated with levels of soil P and K.

The citrus nematode *Tylenchulus semipenetrans*, causal agent of 'slow decline', is found in most citrus producing regions of the world and is associated with leaf wilting and drop, especially during environmental stress, gradual dieback of the canopy, and reduction in fruit size and yield. *T. semipenetrans* Cobb was first reported in Florida in 1913 (Cobb, 1913). Byars (1921) found *T. semipenetrans* in three citrus plantings where rootstocks had been imported from other states and countries but not in the major citrus-producing regions of Florida. During the 1940s the citrus nematode was associated with citrus roots from groves with spreading decline (Suit et al., 1947; Suit et al., 1948), but was later shown to produce symptoms different from those of trees affected by that disease (Suit et al., 1950). Taylor (1944) found *T. semipenetrans* associated with citrus roots collected near Orlando, FL and suggested that the nematode was more widely distributed than had been realized. Based on Florida Dep. of Agric. survey records for *Radolpholus citrophilus*, *T. semipenetrans* was reported in 26% of 3000 groves or nurseries in 35 counties of Florida in 1948 (Hannon, 1948); in 21% of 11 353 ha for 5204 groves in 28 counties in 1960 (Hannon, 1960); in 20% of 13 764 ha for 6099 groves in 29 counties in 1962 (Hannon, 1962); and in 53% of 1580 groves in 26 counties in 1967 (Tarjan, 1967). Most recently, an eleven-year survey of phytoparasitic nematodes in Florida groves (Esser et al., 1993) detected *T. semipenetrans* in 26% of 1186 groves.

Although the citrus nematode has been reported on native plants like climbing hempweed (Chitwood and Birchfield, 1957) and cabbage palms (Esser, 1964) as possibly endemic to Florida, there is no evidence that these populations can infect citrus. For example, *T. palostris* and *T. graminis*, found on native hosts in Florida, do not infect citrus but were considered to be *T. semipenetrans* until 1988 (Inserra et al., 1988). *T. semipenetrans* is spread primarily on infected nursery stock (Hannon, 1962) and contaminated equipment. The nematode does not spread quickly within groves or between groves, but can survive for up to 18 mo. in moist soil stored in clay pots in the greenhouse and up to 31 mo. in field plots free of citrus feeder roots (Hannon, 1964).

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Most of the above surveys conducted by the Florida Dep. of Agric. for burrowing nematode provided information as well about the incidence of the citrus nematode. Groves were sampled based on visual symptoms of spreading decline, a disease caused by the burrowing nematode. However, since no extensive field survey specifically for *T. semipenetrans* has yet been reported in Florida, this survey was undertaken to estimate the incidence of the citrus nematode in Florida citrus groves, using current sampling and nematode-extraction methods.

MATERIALS AND METHODS

Fifty mature citrus groves, ten in each of five central (Lake, Polk), east coastal (Indian River, St. Lucie) and south central (Hendry) Florida counties, were sampled from May to Aug. 1983 for soil and root stages of *T. semipenetrans*. Selected groves represented a cross section of each county in terms of soil series, grove age and condition, rootstock/scions and management practices, except that no groves had been treated with aldicarb. At each site 20 trees within an 8 ha block of approximately 2000 trees were selected, using a random number table to choose numbered trees on a grove map. Eight samples per tree, consisting of soil and roots taken with a narrow blade shovel within the dripline to a 30-cm depth, were subsampled to provide a 1-L sample for analysis. A total of 20 samples per grove or 1000 combined soil/root samples from fifty groves was analyzed for citrus nematodes at the Nematode Assay Laboratory, Univ. of Florida, Gainesville, FL. Two additional soil samples per tree were combined to provide two 1L samples per grove for soil nutrient analysis.

Nematode populations obtained from soil samples (1000) and root samples (1000) were counted separately. Second-stage juvenile and male nematodes were extracted from soil samples by decanting and density flotation (Jenkins, 1964). Juveniles and males hatching from eggs within egg masses on root samples were obtained by incubation (Goodey, 1963). Site infestation was defined as the presence of one or more citrus nematodes in at least one of the 20 root or soil samples per grove. Levels of extractable P, K, Ca, Mg and Cu in the soil samples were determined using the Mehlich 1 extraction method (Hanlon et al., 1991).

RESULTS AND DISCUSSION

Citrus nematodes were detected in 45 of 50 groves (90%), either in soil (42/50 groves) or root (45/50 groves) samples (Table 1). Of the 1000 trees sampled, *T. semipenetrans* was recovered more frequently ($P = 0.01$) from root samples (548) than from soil samples (475) (Table 2). Average nematode population levels within each county for groves infested by citrus nematodes varied considerably (Table 3). However, normal seasonal variation in population density of citrus nematodes (Duncan et al., 1993) make it difficult to compare regional population differences from data collected during a 4-mo interval.

A large majority of *T. semipenetrans*-infested groves contained trees beneath which no *T. semipenetrans* were detected from samples of soil or roots (Fig. 1). Indeed, citrus nematodes were not detected in either soil or root samples from at least half of the trees in one third of the groves. The patchy distribution of infected trees probably resulted from random inoculation events (planting of infected nursery trees, equipment operators moving infested soil) rather than perturbations that reduced nematode populations on some trees (Duncan et al., 1989, 1995).

A clear discrepancy between the proportion of infested groves detected in this and previous studies (Hannon, 1962; Tarjan, 1967) may be due partly to a high intensity of sampling in the present study that detected nematodes in groves with a small number of infected trees. For example, the most recent survey detected *T. semipenetrans* in only 26% of Florida groves, based on samples taken from just five sites per grove (Esser et al., 1993). That detection rate is likely an underestimate of

Table 1. Occurrence of *Tylenchulus semipenetrans* in 50 Florida citrus groves.

	Central Ridge Counties		Flatwoods Counties			Occurrence/50 groves
	Lake	Polk	Indian River	St. Lucie	Hendry	
	Occurrence/10 groves/county					
100 cm^3 soil samples	9	8	10	8	7	42
10 g root samples	10	9	10	8	8	45
Percent infestation/county	100	90	100	80	80	

Table 2. Occurrence of *Tylenchulus semipenetrans* in soil and root samples.

	Central Ridge Counties		Flatwoods Counties			Occurrence/1000 samples
	Lake	Polk	Indian River	St. Lucie	Hendry	
	Occurrence/200 samples/county (%)					
100 cm^3 soil samples	73 (36)	124 (62)	112 (56)	124 (62)	42 (21)	475/1000 (48)
10 g root samples	101 (51)	136 (68)	131 (65)	118 (59)	62 (31)	548/1000 (55)

Table 3. Population levels - mean† and standard error - of *Tylenchulus semipenetrans* in Florida citrus groves.

Central Ridge Counties		Flatwoods Counties		
Lake	Polk	Indian River	St. Lucie	Hendry
		100 cm^3 soil samples		
369 (422)	3365 (4829)	468 (598)	4032 (5507)	60 (95)
369 (133)	3745 (1654)	468 (188)	5040 (2036)	75 (36)
		10 g root samples		
3981 (2413)	10 970 (7952)	2584 (868)	3598 (1257)	392 (125)
3982 (7632)	9799 (8477)	2584 (2746)	2910 (3461)	313 (351)

†10 groves for Lake and Indian River counties; 9 for Polk County; 8 for Hendry and St. Lucie counties.

the incidence of *T. semipenetrans*, given the highly patchy distribution of the nematode shown in the present study. Nevertheless, a small number of groves was sampled in this study compared to previous studies. Moreover, newly-established citrus regions were not included in this survey. A large portion of the citrus industry in Florida has moved south, following several severe freezes since 1985.

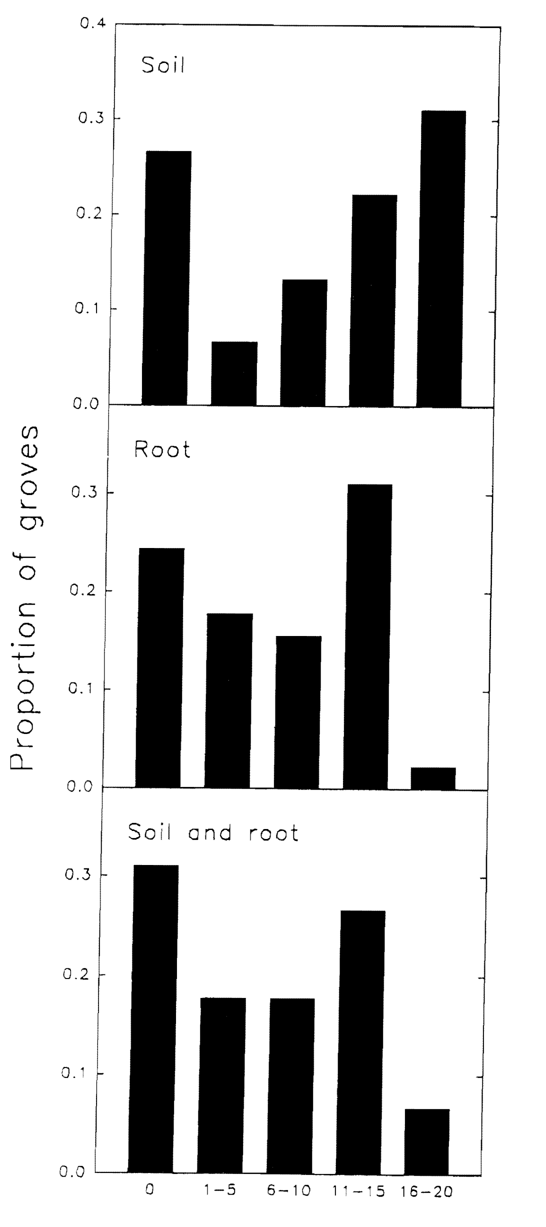

Fig. 1. Proportion of groves containing various categories of non-infested trees.

Citrus nematodes do not infect native plants in newly planted areas (Inserra et al., 1988). Recently planted groves should not be infested by *T. semipenetrans*, because commercial trees have been certified as nematode-free since 1957 by the Florida Dep. of Agric. and Consumer Services, Div. of Plant Industry. Recent widespread replanting with a nematode-resistant rootstock, 'Swingle' citrumelo, has also reduced the incident of *T. semipenetrans*, even in older citrus regions (L. W. Duncan and R. Inserra, unpublished data). Thus, while this study illustrates the importance of sampling intensity in estimating the incidence of these nematodes, the results are now primarily of historical interest.

Population density of *T. semipenetrans* is affected by rootstock and soil texture, which tend to be regionally consistent. Linear correlations ($P < 0.05$) existed between log-transformed citrus nematode population densities and levels of extractable K, Cu, and soluble salts, in the infested groves of Indian River, St. Lucie and Hendry counties (Flatwood regions) (Table 4). On the central ridge (Lake and Polk counties), nematode density was correlated with levels of extractable P and K.

Relationships between *T. semipenetrans* and soil salinity are well-documented (Mashela et al., 1992). Salinity is generally lower on the central ridge than in the Flatwoods (Table 5), which may account for the weak relationship between salinity and *T. semipenetrans* on the central ridge. Similarly, organic matter content of soil can increase the rate of population growth for citrus

Table 4. Linear correlation coefficients† between mean nematode population densities ($\log_e$) and eight edaphic variables from groves on the Central Ridge and in the Flatwoods.

	pH	OM	P	K	Mg	Cu	Ca	SS
		%	------------	------------	(mg kg^{-1})	------------	------------	ds m^{-1}
Ridge‡	0.25	0.39	0.45[¶]	0.50[¶]	0.25	0.42	0.39	0.30
Flatwoods[§]	0.37	0.27	0.26	0.46[¶]	0.33	0.41[¶]	0.29	0.49[¶]

†Groves in which citrus nematodes were not detected were omitted from the analysis.

‡N = 9

[§]N = 26

[¶]$P < 0.05$

Table 5. Soil characteristics - mean and standard error - of Florida citrus groves infested by *Tylenchulus semipenetrans*.

	Central Ridge†	Flatwoods‡
pH	6.84 (0.44)	6.80 (.10)
Organic matter (%)	1.34 (0.08)	1.74 (.23)
Soluble salts, ppm (ds m^{-1})	141.1 (12.5)	197.1 (10.3)
Soil nutrient levels (mg kg^{-1})		
P	121.6 (24.1)	69.8 (18.4)
K	25.7 (2.7)	43.7 (6.5)
Mg	130.6 (21.4)	140.3 (22.7)
Cu	21.5 (3.05)	14.42 (2.6)
Ca	913 (121)	1562 (257)

†N=19
‡N=26

nematodes (O'Bannon, 1968). The lack of a significant correlation between population density and organic matter in this survey is probably due to the low levels of organic matter in these soils. Although the correlations between population density and pH were not significant for either region, the correlation was significant (r = 0.29, n = 45) for the pooled data, which is consistent with previous reports (Van Gundy et al., 1964).

The positive correlation between P and nematode population density in this study occurred at levels of extractable P that were shown to be detrimental to the nematode in controlled studies, where nematode population development was related to soil P in a quadratic manner (Martin and Van Gundy, 1963). The quadratic relationship may have reflected successive response of weak trees, unsuitable for nematode development in P deficient soils; stronger trees, but without adequately functioning defense mechanisms at high P levels; and healthy trees with functional defense mechanisms at intermediate P levels. However, levels of P in citrus groves in Florida tend to be very high due to long-term application of P in fertilizer. Trees are almost never P deficient. Citrus nematode populations build gradually over long intervals in groves, and P levels also increase as fertilizer is applied over time. Thus, the relationship we found may be due to a positive relationship between age of grove and both P and nematode density. A similar explanation may apply to the correlation with extractable soil Cu, which accumulates in groves over time.

CONCLUSIONS

In conclusion, we found a higher proportion of groves to be infested by citrus nematodes than previously reported in several old citrus-growing regions of Florida. The spatial patterns for infected trees in many of these groves were highly aggregated. This and another recent study for citrus (Duncan et al., 1996) illustrate the importance of sampling intensity as well as survey size to accurately estimate the incidence of nematodes with highly aggregated population distributions and to plan nematicide applications and cultural practices to manage citrus nematodes in a cost-effective program. Our findings also underscore the importance of rootstock certification to limit the spread of these nematodes in newly-planted regions of the state.

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Yield and Petiole-Sap Nitrate Levels of Tomato with N Rates Applied Preplant or Fertigated

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ABSTRACT

Recommended ranges for nitrate-N concentrations in the petiole sap of tomato have been published based on data from south Florida. Data from north Florida are necessary to confirm that these ranges apply to all areas of the state. Our objectives were to compare published recommended ranges of petiole-sap nitrate-N for tomato with ranges found for highest yield in our tests, and to determine the correlations between yield, petiole-sap nitrate-N, and N rates for spring and fall tomato crops in north Florida. A spring crop (cv. Colonial) and fall crop (cv. Solar Set) of tomato were grown at the North Florida Res. and Educ. Center (NFREC), Quincy in 1995 with drip irrigation, using recommended cultural practices for raised beds with polyethylene mulch and stakes. Rates of N were 0, 67, 134, 202, and 269 kg ha^{-1} (0, 60, 120, 180, and 240 lb acre^{-1}). Two methods of application were employed for the spring crop; one method was to apply 100% of the N preplant, while the other was to apply 40% of the N preplant with six injections of liquid N (each 10% of the total) into the drip system as ammonium nitrate at 3, 5, 7, 9, 11, and 13 weeks after transplanting. The fall crop received only the 100% preplant N treatments. Petiole samples from each crop were collected at 2-wk intervals between 4 and 14 wk after transplanting. Nitrate in the petiole sap was determined with a hand-held, battery-operated, nitrate ion meter. Market yield for each crop was determined at three harvest dates. The correlation between yield and petiole-sap nitrate (range of r = 0.459 to 0.896) and between petiole-sap nitrate and fertilizer N were significant at $P \leq 0.01$ for both spring and fall crops between 4 and 10 wk after transplanting. However, there was no correlation between these variables beyond 10 wk after transplanting. Yields were much lower for the fall crop (maximum = 37 Mg ha^{-1}) as compared with the spring crop (maximum = 63 Mg ha^{-1}). Furthermore, yield response to N rates was much stronger for the spring crop than for the fall crop. There was better agreement between published recommended ranges of petiole-sap nitrate-N and ranges of petiole-sap nitrate-N for highest yield of the spring crop than for the fall crop.

Nitrogen (N) has a major influence on tomato (*Lycopersicon esculentum* Mill) yield in Florida. The Coop. Ext. Service recommendation (Hochmuth and Hanlon, 1995) for tomato N fertilization is 196 kg ha^{-1} (175 lb acre^{-1}) and yet, according to one survey, commercial growers apply N to tomato in the range of 308 to 560 kg ha^{-1} (275 to 500 lb acre^{-1}), with the most common rate being ≈400 kg ha^{-1} (350 lb acre^{-1}) (Everett, 1976). Excessive N fertilization of commercial tomato crops is wasteful and poses a threat to local water supplies. Plant tissue analysis has long been used as a tool to manage N fertilization of crops because of the difficulties encountered in assessing soil N availability. However, most quick tests are qualitative, while conventional tests are time-consuming and require several days for return of results. The recent development of a small battery-operated nitrate ion meter (Cardy ion meters) makes it possible to quantitatively determine the N concentration of plant sap on the same day samples are taken.

Recommended ranges for nitrate-N concentration in petiole sap of tomato have been published (Hochmuth, 1994), based on data from south Florida (Hochmuth et al., 1988) where fertilizer N rates were 224 and 336 kg ha^{-1} (200 and 300 lb acre^{-1}). Additional data are necessary to determine nitrate concentration in tomato petiole sap with lower rates of N fertilizer, including a zero N level. Data from north Florida are necessary to confirm whether or not the recommended petiole-sap nitrate-N ranges for tomato apply to all areas of the state. Also, data showing least significant differences for petiole-sap nitrate-N have not yet been published for tomato in Florida.

Objectives of this research were to: (1) determine the influence of fertilizer N rates and application methods on yield and petiole-sap nitrate-N concentration of tomato; (2) examine correlation between petiole-sap nitrate-N concentration and yield of tomato; (3) compare published recommended ranges of petiole-sap nitrate-N concentration of tomato with ranges found for highest yield in these tests; and (4) compare response to N fertilization of spring and fall tomato crops.

METHODS

Tomato plants were transplanted 21 Mar. 1995 (spring crop) and 18 July 1995 (fall crop) in research plots located at the North Florida Res. and Educ. Center, Quincy. The production system included drip irrigation, polyethylene mulch (black in spring and white in fall), and stakes to support and maintain plants in an upright position when plants were tied to the stakes with twine. Recommended cultural and pest-control practices were applied uniformly to all treatments (Hochmuth, 1988). For the spring crop, N rates were 0, 67, 134, 202, and 269 kg ha^{-1} (0, 60, 120, 180, and 240 lb acre^{-1}). Two methods of N application were employed at each N rate; one as 100% preplant incorporated into the bed, and the other as 40% of total N preplant. The 40% preplant N treatments received six injections of liquid N (each at 10% of total N) into the drip system at 3, 5, 7, 9, 11, and 13 weeks after transplanting. The fall crop had the same N rates as the spring crop, but only five treatments, each applied as 100% of N preplant. The source of N for both crops and all treatments was ammonium nitrate.

Rows of tomato plants were 1.83 m (6 ft) apart, width of the mulched bed was 0.91 m (3 ft), each single-row plot contained 18 plants 0.51 m (20 inches) apart, and only the 12 center plants were harvested for yield. Cultivars were 'Colonial' for the spring crop and 'Solar

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Set' for the fall crop. There were three harvests for each crop, with tomatoes being graded into culls, medium, large, and extra large fruit.

The fifth or sixth leaf from the tip of each of 10 tomato plants was obtained from each plot on each sampling date in each experiment for petiole-sap nitrate-N determinations. Sampling dates were 4, 6, 8, 10, 12, and 14 weeks after transplanting for the spring crop and 4, 6, 8, 10, and 12 weeks after transplanting for the fall crop. Petioles were chopped, sap expressed with a hydraulic press, a few drops placed on the nitrate meter's electrodes, and nitrate ion concentration read directly using a digital meter. Nitrate ion concentration in the petiole sap was converted to nitrate-N concentration by multiplying by 0.226.

The experimental design was a randomized complete block with four replicates (Steel and Torrie, 1960). Analysis of variance procedures were used to evaluate treatment means for yields and petiole-sap nitrate (Freed et al., 1989). F-tests were employed to determine if N rate significantly influenced yield and petiole-sap nitrate concentration. Simple regression analysis was used to determine correlation coefficients between yield and petiole-sap nitrate concentrations, and between N rate and petiole-sap nitrate concentrations.

RESULTS AND DISCUSSION

Yield response of tomato to N fertilizer between zero and 67 kg ha^{-1} was significant ($P \leq 0.05$) for both the spring and fall crops (Table 1). Yield difference for the spring crop between 40 and 100% preplant N was significant ($P \leq 0.05$) only at the 67 kg N ha^{-1} rate, with a 7 Mg ha^{-1} advantage for the 100% preplant N. Highest yield occurred with 40% preplant N at 202 kg ha^{-1}, which is about equal to the N rate (196 kg ha^{-1}) recommended by the Coop. Ext. Service (Hochmuth and Hanlon, 1995). For the fall crop, yield did not respond to N fertilization above the 67 kg ha^{-1} rate. Yield may have been limited by the extremely high day and night temperatures that occurred during the 1995 fall growing season.

A positive yield response to fertilizer N did not occur for the first harvest of either crop (Table 2). For the second and third harvests, fertilizer N affected yield much more in the spring than the fall. This lends support to the hypothesis that factors other than lack of fertilizer N were limiting yield for the fall crop.

Tomato yields were highly correlated (positive r) with petiole-sap nitrate within 4 to 10 wk after transplanting for both the spring and fall crops (Table 3). The highest correlation occurred at 6 wk after transplanting for both crops. The absence of a positive correlation between yield and petiole-sap nitrate of tomato after 10 wk of growth suggested that there was no value in further sample collection. However, the high correlation between yield and petiole-sap nitrate during the first 10 wk of growth strongly supports the hypothesis that petiole-sap tests for nitrate are useful for managing midseason N fertilization of tomatoes.

Petiole-sap nitrate in tomato was highly correlated with fertilizer N rates during the four to 10 wk growth period for both spring and fall crops, but there was no correlation after 10 weeks (Table 4). In view of this outcome, it appears that adding fertilizer N after 10 wk of growth is not likely to influence plant response of tomato whether grown in spring or fall. These observations are in agreement with results in Table 3, showing no relationship between yield and petiole-sap nitrate level of tomato after 10 wk of growth. Since first harvest

Table 2. Yield response of tomato to fertilizer N by harvest date and fruit grade.

Harvest number	Fruit size	F-Value	
		Spring crop	Fall crop
1	medium	0.45 ns	7.99**¶
1	large	0.96 ns	1.11 ns
1	x-large	1.46 ns	1.38 ns
2	medium	1.25 ns	0.67 ns
2	large	3.80**	3.65*
2	x-large	5.80**	4.14*
3	medium	9.81**	2.36 ns
3	large	6.34**	7.54**
3	x-large	8.04**	1.38 ns

¶Yield response of fall crop to fertilizer N at first harvest, medium grade, was negative (highest yield with zero N).

**, *Significant at the 0.01 and 0.05 alpha levels, respectively; ns, not significant at 0.05 alpha level.

Table 1. Yield response of tomato fertilizer N rate as shown for the 1995 spring crop with 40 and 100% of N preplant (PP) and for the fall crop with 100% of N preplant.

Fertilizer N	Spring crop yield		Fall crop yield
	40% PP	100% PP	100% PP
kg ha^{-1}	Mg ha^{-1}		
0	26¶	—	21
67	40	47	35
134	51	54	33
202	63	59	37
269	61	62	37
$LSD_{0.05}$	6.8	6.8	6.6

¶1.0 Mg ha^{-1} = 36 boxes acre^{-1} (25 lb box^{-1}).

Table 3. Yield response of tomato to petiole-sap nitrate for the 1995 spring and fall crops as shown by the correlation coefficient (r) for linear regression at each petiole sampling date.

Sampling date (weeks after planting)	Correlation coefficient (r)	
	Spring crop	Fall crop
4	0.689**	0.789**
6	0.896**	0.816**
8	0.710**	0.624**
10	0.587**	0.459*
12	0.061 ns	0.11 ns
14	-0.446**	—

**,*Significant at the 0.01 and 0.05 alpha levels, respectively. ns, not significant.

Table 4. Response of petiole-sap nitrate for 1995 spring and fall tomato crops to fertilizer N rates at each sampling date.

Sampling date (weeks after planting)	F-value	
	Spring crop	Fall crop
4	5.07**	18.4**
6	23.0**	17.1**
8	6.05**	16.3**
10	10.9**	5.57**
12	0.97 ns	1.79 ns
14	1.20 ns	—

**,*Significant at the 0.01 and 0.05 alpha levels, respectively. ns, not significant.

occurred after 12 wk following transplanting for both the spring and fall crops, there was limited time for plant yield response to fertilizer N applied after 10 wk growth.

Petiole-sap nitrate-N remained high (near 1000 mg L^{-1}) between four and eight weeks after transplanting, before dropping more than 50% by 10 weeks at fertilization rates of 202 and 269 kg N ha^{-1} for the spring crop. Petiole-sap nitrate-N continuously dropped by 20 to 30% between sampling dates for the fall crop during a similar growth period (Table 5). Since different cultivars were used for the spring and fall crops, the reason for the different petiole-sap nitrate profiles could have been genetic as well as environmental. However, cultivars that perform best in spring are not generally suitable for tomato production during the high summertime temperatures that occur during the growing season of a fall crop. The average least significant difference ($LSD_{0.05}$) in petiole-sap nitrate-N concentrations between 4 and 10 wk after transplanting was 211 mg L^{-1} for the spring crop and 202 mg L^{-1} for the fall crop. Since yield was not related to petiole-sap nitrate concentration after 10 weeks growth, the LSD's for 12 and 14 weeks are of little value.

For the spring crop, the highest yield was produced at 202 kg N ha^{-1}, which was significantly different ($P \leq 0.05$) from the yield at 134 kg N ha^{-1}, though not significantly different from the yield at 269 kg N ha^{-1}. Therefore, we may use the seasonal petiole-sap nitrate-N concentration profile of the 202 kg N ha^{-1} treatment to determine recommended ranges of petiole-sap nitrate-N. Since readings between 4 and 8 wk were fairly constant, we took the average (1060 mg L^{-1}) and used the range of 960 mg L^{-1} to 1160 mg L^{-1} to correspond with an LSD of approximately 200 mg L^{-1} for the 4 to 8 wk growth period. The average for 8 and 10 wk (775 mg L^{-1}) was used to determine the 9th wk sample range of 675 to 875 mg L^{-1}. The 10 week sample range was determined to be 300 to 500 mg L^{-1}.

For the fall crop, we could use the petiole-sap nitrate-N concentrations for either the 67 kg N ha^{-1} treatment or the 202 kg N ha^{-1} treatment to determine recommended ranges. The 67 kg N ha^{-1} fertilizer treatment produced a yield significantly higher than at zero N, but not significantly different from yields for higher N treatments. However, the 202 kg N ha^{-1} treatment may produce the highest fall crop yield in years with lower summer temperatures. Recommended ranges of petiole-sap nitrate-N for the fall crop were calculated in a similar manner to those for the spring crop. For the 67 kg N ha^{-1} treatment, petiole-sap nitrate-N ranges were: at 4 to 5 wk after transplanting, 776 to 976 mg L^{-1}; at 6 to 7 wk, 476 to 676 mg L^{-1}; and at 8 to 10 wk, 260 to 460 mg L^{-1}. Ranges for the 202 kg N ha^{-1} treatment were: at 4 to

Table 5. Sap test nitrate N in tomato petioles by sampling date and fertilizer N rate for 1995 spring and fall crops.

Sampling date (wks after planting)	Fertilizer N rate (kg ha^{-1})					
	0	67	134	202	269	$LSD_{0.05}$
	NO_3-N (mg L^{-1})					
	Spring crop (40% of N preplant)					
4	678	938	910	1130	1147	202
6	197	407	780	944	961	185
8	492	616	774	1028	1079	296
10	253	203	159	356	520	162
12	385	452	222	407	541	318
14	618	424	316	251	418	314
	Spring crop (100% of N preplant)					
4	678	966	1124	1040	1147	202
6	197	661	932	938	1153	185
8	492	797	1028	1277	1028	296
10	253	254	373	441	746	162
12	385	254	427	396	525	318
14	618	346	232	410	280	314
	Fall crop (100% of N preplant)					
4	389	876	972	1203	1119	229
6	154	576	689	876	881	222
8	225	367	588	684	695	158
10	286	349	231	559	554	199
12	435	267	205	490	509	218

5 wk after transplanting, 1100 to 1300 mg L^{-1}; at 6 to 7 wk, 776 to 976 mg L^{-1}; and at 8 to 10 wk, 500 to 700 mg L^{-1}.

For the spring crop, the range of optimum petiole-sap nitrate-N for the growth period 4 to 8 wk (960 to 1160 mg L^{-1}) approached the published recommended range (1000 to 1200 mg L^{-1}) for first buds (Hochmuth, 1994). The 9 wk range (675 to 875) was equivalent to the published range (600 to 800) for first open flowers. However, the 10 wk range (300 to 500) overlapped the published ranges for one-inch fruit (400 to 600), two-inch fruit (400 to 600), and first harvest (300 to 400). For the fall crop, ranges for the 202 kg N ha^{-1} treatment agreed with published ranges during early season, but tended to be higher than published ranges later in the season. Ranges for the fall crop at 67 kg N ha^{-1} were generally lower than published ranges.

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Management of Citrus Blight with Soil Amendments

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ABSTRACT

Six amendments, two rates each, were applied, prior to planting, to the soil surface of a new citrus grove site and plowed 1.2 m deep and 1.6 m wide down the row in August 1984. Valencia orange on rough lemon rootstock was planted in the grove in February 1985. Blight began appearing in the grove in 1990 and data were taken on its occurrence between October 1990 and April 1994. Between October 1990 and April 1992 blight ratings were low. The low calcium humate (1120 kg ha^{-1}), high peat (261 775 kg ha^{-1}), and low peat (81 805 kg ha^{-1}) treatments reduced blight development the most during the study, although low peat significantly suppressed it more consistently compared to the control. The grower used reset trees to replace those with moderate to severe blight symptoms but none was needed in the low and high peat treatments and the low calcium humate treatment. Treatment rows at this site alternated with non-tilled, nontreatment rows. Blight developed in both the non-tilled and deep-tilled control treatments at similar rates. The suppression of blight by peat confirms previous observations that blight is suppressed at flatwoods sites containing high levels of peat. Peat in this test may have suppressed blight by reducing water stress in the root zone, enhancing biological buffering, reducing root disease, and/or affording a better level of plant nutrition.

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INTRODUCTION

Until recently, little research was conducted in Florida to study the effects of composts, amendments, and waste materials on citrus tree health and development. Current regulations limiting the use of soil-applied pesticides and the disposal of landfill materials have increased the interest in agricultural use of composts and other soil-applied amendments for citrus and other crops (Hoitink and Fahy, 1986; Hoitink et al., 1991; Ozores-Hampton et al., 1994; Roe et al., 1993).

Most Florida citrus soils are sandy, slightly acidic, and have poor water-holding and low cation-exchange capacities (Peech, 1939). These sandy soils can be modified with amendments and composts to improve structure, fertility, and other factors that may enhance tree health, production, and growth. At present, soil alteration in the citrus-producing areas of Florida is limited to deep-tillage alone, conducted by some growers in the flatwoods shallow soils along both the Atlantic and Gulf coasts (R. Pelosi, personal communication, 1989); and to experimental use of such amendments as humates (Bateman, 1988; Webb et al., 1988), clays (Childs, 1979), and certain other amendments, including sludges, milorganite, phosphogypsum, lime, and phosphoclay (Gould et al., 1988; Nemec and Lee, 1992; Smith et al., 1989). At one study site near Ft. Meade, preplant deep-mixing of soil to a depth of 1.1 m significantly increased tree growth more than a no-mix control, and was as effective in promoting growth as five deep-mixed soil amendments (Smith et al., 1989). Increased growth in plots with soil mixing only was probably the result of improved soil aeration and reduction in resistance to root penetration (Smith et al., 1989). When blight development was compared in the deep-tillage, deep-tillage plus lime, and surface tillage treatments of the SWAP (Soil-Water-Atmosphere-Plant) experiment at Ft. Pierce, fewer trees developed blight on deep-tilled soil (Cohen et al., 1981).

Benefits from soil-applied composts and amendments include enhanced tree growth and yield, resulting from increased disease resistance and tree health. Application of gypsum to a new citrus grove near St. Cloud, FL resulted in a significant reduction in Phytophthora crown rot symptoms (causal agent = *Phytophthora parasitica* Dast.) compared to the control (Nemec and Lee, 1992). The reduction in crown rot appeared to be due to enhanced Ca and S uptake by the trees. Further studies in other groves indicated that phosphogypsum had no effect on soil propagule numbers of *P. parasitica,* however (Nemec et al., 1990).

The grove at St. Cloud was established with six soil amendments, two rates each, in 1984 and planted in February 1985. Beginning in 1990, blight symptoms began developing at that site and ratings were taken usually twice a year through April 1994, to determine how these soil amendments affected blight occurrence. This study reports results of these blight data.

MATERIALS AND METHODS

The planting site and location have previously been described (Nemec & Lee, 1992). The soil amendments consisted of Florida reed sedge peat (81 805 and 261 775 kg ha^{-1}) from a central Florida site; shrimp hull waste (20 451 and 81 805 kg ha^{-1}); humate (16 361 and 81 805 kg ha^{-1}) mined from Leonardite shale; mined gypsum (1120 and 2240 kg ha^{-1}); calcium humate (1200 and 2240 kg ha^{-1}) sold as Agraset® by Agra Chem. Sales, Avon Park, FL; and bentonite clay (40 902 and 81 805 kg ha^{-1}). The treatments were arranged in a randomized complete block design with six replicates of each treatment. A deep-mixed, no amendment treatment was included as a control. All amendments were applied to the soil surface in a band 1.6 m wide down the center of the rows and plowed 1.2 m deep with a trenching machine in August 1984. Treatment replicates consisted of four trees spaced 7.4 m apart in the row, with each amendment application extending 2.4 m beyond the end of each end-tree site. Each deep-tilled treatment row alternated with a non-tilled nontreatment row. Valencia sweet orange (*Citrus sinensis* (L.) Osb.) on rough lemon (*Citrus limon* (L.) Burm f.) rootstock was planted at the site in February 1985.

Only humate, calcium humate, and gypsum were reapplied to this trial after the initial treatment. Frequency of reapplication through May 1990 and cultural practices conducted at the site have previously been reported (Nemec & Lee, 1992). From 1991 through 1994 these three amendments were reapplied in May each year to the soil surface.

Blight development was rated visually on a scale of 0-3 in tilled and non-tilled rows. Zero represented no symptoms; 1 was applied to early leaf roll and leaf Zn deficiency symptoms; 2 included symptoms ascribed to the No. 1 rating as well as moderate wilting of entire branches, either whole-tree wilt or as sectors; and 3 represented extreme wilt with some dieback. Trees with blight were removed and replaced with reset trees in October 1992, April 1993, and December 1993. Blight was scored a "3" in locations where resets were used for all later evaluations of tree loss to blight.

Blight was confirmed in selected treatments by use of the syringe water-uptake procedure (Lee et al., 1984). Blight ratings used during the time period when water-uptake data were taken were on a scale of 0 - 5, with 0 representing no symptoms and 5 attributed to trees with severe branch dieback.

Blight development on each rating date was analyzed for significance using Duncan's multiple range test. Data on paired treatments were compared using the t test.

RESULTS AND DISCUSSION

Zinc deficiency, an early symptom of blight, appeared in leaves of a few trees in October 1989 and was apparent on more trees in early 1990, but its occurrence coupled with some leaf wilt did not differ among treatments in October 1990 (Tables 1 and 2). Although blight was confirmed for selected treatment trees in July 1990 by water injection (Table 3), visual symptoms alone during early blight development were not good indicators of differences among treatments. Leaf flagging and wilt that occurred alone or with the first symptoms of Zn deficiency could not be directly attributed to blight or to periods of stress during intermittent periods of water deficits and excesses during this study.

By October 1991, symptom increases and, in a few instances, decreases due to transient changes in Zn deficiency and wilt resulted in significant differences among several treatments. In October 1991, the percentage of trees with blight was significantly lower in six treatments compared to the control, but only low peat had a significantly lower mean blight rating (Table 1). In April 1992, mean ratings of five treatments were significantly lower than the control (Table 1); four of these treatments also had a significantly lower percentage of blight that month (Table 2). Increases in mean and percentage blight ratings between October 1992 and April 1994 improved the ability to discriminate real differences among treatments (Tables 1 and 2). By April 1994, the only treatment that had significantly lower mean and percentage ratings than the control was the low peat treatment, which had no detectable blight (Tables 1 and 2). The low calcium humate and the high peat treatments also had low blight ratings. Water uptake patterns for visibly healthy trees in the low and high rate peat treatments in September 1995 confirmed that such trees conducted more water than blighted controls (Table 3).

During the time these ratings were conducted, the junior author (also the owner of this grove) replaced severely blighted trees with healthy resets. Resets were used in only six treatments in October 1992 and April 1993 but, by December 1993, resets had been planted in

Table 1. Mean ratings of citrus blight in the St. Cloud, FL soil amendment field plots between October 1990 and April 1994.

Treatment and rate (kg ha⁻¹)		Rating dates						
		Oct. 1990	Oct. 1991	Apr. 1992	Oct. 1992	Apr. 1993	Dec. 1993	Apr. 1994
Calcium humate	(2240)	0.45a	0.43ab	0.48abc	0.52abc	0.52ab	0.67ab	0.75ab
Calcium humate	(1120)	0.05a	0.10ab	0.00d	0.10abc	0.10b	0.08b	0.17ab
Bentonite clay	(81 805)	0.18a	0.18ab	0.27abcd	0.27abc	0.32ab	0.46ab	0.54ab
Bentonite clay	(40 902)	0.08a	0.08ab	0.18bcd	0.22abc	0.22ab	0.25ab	0.28ab
Gypsum	(2240)	0.35a	0.38ab	0.35abcd	0.38abc	0.43ab	0.38ab	0.42ab
Gypsum	(1120)	0.05a	0.08ab	0.18abcd	0.30abc	0.25ab	0.46ab	0.54ab
Humate	(81 805)	0.18a	0.13ab	0.13bcd	0.23abc	0.23ab	0.46ab	0.63ab
Humate	(16 361)	0.13a	0.05ab	0.18abcd	0.18abc	0.23ab	0.29ab	0.38ab
Peat	(261 775)	0.17a	0.08ab	0.08bcd	0.05bc	0.05b	0.17ab	0.17ab
Peat	(81 805)	0.05a	0.00b	0.00cd	0.00c	0.00b	0.00b	0.00b
Shrimp shells	(81 805)	0.30a	0.35ab	0.30abcd	0.40abc	0.43ab	0.42ab	0.54ab
Shrimp shells	(20 451)	0.37a	0.37ab	0.52ab	0.60ab	0.65a	0.67ab	0.75ab
Control		0.43a	0.47a	0.65a	0.65a	0.73a	0.88a	0.92a

Blight ratings based on a visual scale of 0 - 3. 0 = no symptoms, 1 = early leaf roll and leaf Zn deficiency, 2 = moderate whole-branch leaf wilt, and 3 = extreme wilt with some dieback. Values sharing the same small letter are not statistically different at $P = 0.05$, Duncan's multiple range test.

Table 2. Percentage of citrus blighted trees between October 1990 and April 1994 at the St. Cloud, FL field plots.

Treatment and rate (kg ha⁻¹)		Rating dates						
		Oct. 1990	Oct. 1991	Apr. 1992	Oct. 1992	Apr. 1993	Dec. 1993	Apr. 1994
Calcium humate	(2240)	16.7a	16.7ab	16.7abc	20.8ab	20.8ab	25.0ab	29.2ab
Calcium humate	(1120)	4.2a	8.3b	0.0c	8.3ab	8.3ab	8.3ab	8.3ab
Bentonite clay	(81 805)	12.5a	12.5ab	12.5abc	12.5ab	16.7ab	20.8ab	20.8ab
Bentonite clay	(40 902)	4.2a	4.2b	8.3abc	12.5ab	12.5ab	12.5ab	16.7ab
Gypsum	(2240)	16.7a	16.7ab	12.5abc	12.5ab	16.7ab	12.5ab	16.7ab
Gypsum	(1120)	4.2a	8.3ab	8.3abc	16.7ab	12.5ab	16.7ab	20.8ab
Humate	(81 805)	8.3a	4.2b	4.2bc	12.5ab	12.5ab	25.0ab	25.0ab
Humate	(16 361)	8.3a	4.2b	12.5abc	8.3ab	12.5ab	12.5ab	16.5ab
Peat	(261 775)	12.5a	4.2b	4.2bc	4.2b	4.2b	8.3ab	8.3ab
Peat	(81 805)	4.2a	0.0b	0.0c	0.0b	0.0b	0.0b	0.0b
Shrimp shells	(81 805)	12.5a	16.7ab	12.5abc	16.7ab	16.7ab	16.7ab	20.8ab
Shrimp shells	(20 451)	16.7a	16.7ab	20.8ab	20.8ab	20.8ab	25.0ab	33.3a
Control		25.0a	29.2a	25.0a	29.2a	29.2a	33.0a	33.3a

Percentage blighted trees determined from rating based on 0 - 3. 0 = no symptoms; 1 = early leaf roll and leaf Zn deficiency; 2 = moderate whole-branch leaf wilt; and 3 = extreme wilt with some dieback. Values sharing the same small letter are not statistically different at $P = 0.05$, Duncan's multiple range test.

10 treatments (Table 4). No resets were required in the low calcium humate and the high and low peat treatments. These were the three treatments with the lowest mean and percentage blight ratings (Tables 1 and 2). The grower's decision not to plant resets in these treatments is a recognition that symptoms were not present or severe enough to warrant tree removal.

Blight development in the non-tilled alternate rows was significantly higher than in the deep-tilled rows of all treatments by December 1993 and April 1994 (Table 5). However, blight development in the non-tilled rows was not significantly different from its occurrence in the deep-tilled control rows, which is the only deep-tilled treatment appropriate for comparison with the non-tilled rows (Table 5). The combined presence of amendments in the deep-tilled rows reduced blight sufficiently to account for its lower occurrence compared to levels in the deep-tilled control and non-tilled rows.

Trees in the non-tilled rows were visually slower in growth compared to trees in the tilled rows, although

Table 3. Water uptake by the syringe injection procedure for Valencia on rough lemon trees in the St. Cloud, FL field plots.

Treatment and rate (kg ha⁻¹)		Mean tree condition	Water uptake (ml/30 sec)
		11 July 1990	
Control		0.0	5.0*
Various amendments		2.0	1.8
		14 September 1995	
Peat	(81 805)	0.0	6.62a
Peat	(261 775)	0.0	7.12a
Control (healthy-appearing)		0.0	7.48a
Control (blight-diseased)		2.6	2.90b

Blight rating based on a visual scale of 0 - 5. 0 = no symptoms; 1-2 = early leaf roll and Zn deficiency; 3-4 = moderate leaf wilt; and 5 = severe branch dieback. Treatment means for 11 July 1990 were compared by the t test: $*P = 0.05$; and treatment means for 14 September 1995 were compared by Duncan's multiple range test, with values sharing the same small letter not being statistically different at $P = 0.05$. Data are the means for five trees.

Table 4. Percentage of citrus resets used to replace trees with severe blight in each treatment, October 1992 to December 1993 at the St. Cloud, FL field plots.

Treatments and rate (kg ha⁻¹)		Percentage resets per treatment		
		October 1992	April 1993	December 1993
Calcium humate	(2240)	12.5a	12.5a	8.3ab
Calcium humate	(1120)	0.0b	0.0b	0.0b
Bentonite clay	(81 805)	0.0b	0.0b	12.5ab
Bentonite clay	(40 902)	0.0b	0.0b	4.2b
Gypsum	(2240)	8.3ab	8.3ab	8.3ab
Gypsum	(1120)	0.0b	0.0b	8.3ab
Humate	(81 805)	4.2ab	4.2ab	4.2ab
Humate	(16 361)	0.0b	0.0b	8.3ab
Peat	(261 775)	0.0b	0.0b	0.0b
Peat	(81 805)	0.0b	0.0b	0.0b
Shrimp shells	(81 805)	4.2ab	4.2ab	8.3ab
Shrimp shells	(20 451)	8.3ab	8.3ab	20.8a
Control		8.3ab	8.3ab	12.5ab

Values sharing the same small letter are not statistically different at $P = 0.05$, Duncan's multiple range test.

Table 5. Comparison of blight in deep-tilled treatments and non-tilled treatment rows of the St. Cloud, FL soil amendment plots in December 1993 and April 1994.

Tillage treatment	No. trees in each disease category[z]				Total trees	Mean blight rating (0-3)	Percentage blight
	0	1	2	3			
		December 1993					
Deep-tilled (control)	16	1	1	6	24	0.88a	33.0a
Deep-tilled (all treatments)	260	12	9	31	312	0.40b	17.0b
Non-tilled[y]	308	17	12	85	416	0.67a	27.1a
		April 1994					
Deep-tilled (control)	16	1	0	7	24	0.92a	33.0a
Deep-tilled (all treatments)	252	12	10	38	312	0.46b	19.2b
Non-tilled[y]	296	17	11	92	416	0.76a	29.0a

[z]Disease ratings (0-3): 0 = no symptoms, 1 = early leaf roll and Zn deficiency, 2 = moderate whole-branch leaf wilt, and 3 = extreme wilt with some dieback. All resets used to replace blight trees were rated 3.
[y]All non-tilled rows includes all border rows.
Values sharing the same small letter are not statistically different at $P = 0.05$, Duncan's multiple range test.

these growth differences were not documented by measuring trunk caliper. Smith et al. (1989) reported similar results for a grove near Ft. Meade, when tillage alone increased tree size compared to non-tillage.

Observations made by Cohen (1980), that citrus incurred very little blight in a 1 ha area of peat soil in the flatwoods, and Pinckard's report (1982) that experimental application of humus to soil around blight-diseased trees reduced disease symptoms, support the prevention of blight by peat in this study. Neither Pinckard (1982) nor Cohen (1980) provided evidence concerning reasons for this suppression of blight. Furthermore, soil mineral analysis, soil pH, and other soil parameters measured during the first two years in the St. Cloud grove did not suggest reasons for the suppression of blight by peat in this study. The high rate of peat used in this study increased soil organic matter content by 2%, a level perhaps not high enough to measure the small changes in the soil that may affect disease development. However, studies of the flatwoods organic-soil site, following Cohen's (1980) report, have revealed some results of its blight suppressiveness. Healthy tree roots collected in the organic soil were twice the weight of roots from healthy trees remaining in the surrounding high blight-conducive soil (Nemec et al., 1982). Furthermore, the organic soil supported higher populations of pseudomonads, gram negative bacteria, and fungi than did the surrounding sand. The organic soil also had higher levels of Ca, Mg, K, and P and most minor elements versus the surrounding sandy soil. Water-holding capacity was increased in the peat (Nemec et al., 1983).

Improved water-holding capacity, better subsoil nutrition (especially with respect to Ca), a higher level of microflora competitive to *Fusarium solani* (the common root rotting fungus on blight-diseased trees), and possibly other factors are likely responsible for better established fibrous root systems in organic soils. Cohen's (1980) peat site and others like it are similar to compost- and peat-amended soils. Composts available from municipalities, industrial, and agricultural industries have been used to suppress soilborne diseases of floricultural crops (Hoitink et al., 1991), vegetables (Hoitink and Fahy, 1986), and container-grown woody ornamentals (Hoitink et al., 1993). The mechanisms for this disease suppression are principally through increased competition for nutrients and microbiostasis (Hoitink et al., 1993). These peat soils appear to be near-ideal sites on which to continue research concerning the causal relations of blight.

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Soil Solarization and Fumigant Alternatives to Methyl Bromide for Strawberry Fruit Production

E. E. Albregts*, J. P. Gilreath, and C. K. Chandler

ABSTRACT

Soil solarization, methyl bromide-chloropicrin, and combinations of methyl bromide-chloropicrin and solarization were evaluated in a strawberry fruit production study at a site having a long history of soil fumigation. There were few yield differences due to treatments. A high rate of broiler manure reduced fruit yields for the entire season, while a low rate reduced early yields only. The yield reductions for these two treatments appeared to be related to loss of plants due to salinity effects from the manure. Plant vigor in December and February appeared unchanged except for the manure treatments. Weed control in beds was similar for all treatments by mid-April. Sting nematodes in the soil around the plant roots were absent at the end of the harvest season except for those around one plant each in a non-fumigated plot and a 224 kg ha⁻¹ methyl bromide-chloropicrin plot. The fumigation history of the trial area may have contributed to the lack of significant treatment differences.

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Strawberry fruit production in Florida occurs during the months of November through April on about 2000 ha with a farm-gate value of $100 million (Freie and Pugh, 1994). The annual hill cultural system with raised, polyethylene mulched beds and with the soil treated with nematicides or fumigants has been the standard production system since the early 1960's. Methyl bromide-98% and chloropicrin-2% (MC-2) has been the standard soil fumigant since the early 1980's. Previously a 67%-33% methyl bromide-chloropicrin mixture had been used. An MC-2 mixture along with black plastic mulch controls nematodes and most weeds. If soil-borne diseases are a problem, then a 67%-33% mixture may be more appropriate. Methyl bromide-chloropicrin mixtures are easy to apply to a properly prepared soil and give better control of nematodes, weeds, and soil diseases than any other common soil fumigant.

Methyl bromide use is scheduled to be phased out in the next few years because this chemical has been implicated in depletion of the atmospheric ozone layer. If strawberry growers have to use a fumigant other than methyl bromide, nematodes, root diseases, and weeds may build up over time and be more difficult to control.

The phase-out of methyl bromide is expected to have adverse effects on not only the Florida strawberry industry, but also on pepper, tomato, eggplant, cut flower, tree seedling, and vegetable transplant production. Methyl bromide is also used for fumigation of many post-harvest commodities, with no viable control alternative. Approximately 4.5 million kg (10 million lbs) were used in Florida during 1992 (Aerta and Nesheim, 1995).

There are many suggested chemical alternatives to methyl bromide, including metam sodium, ethoprop, and metalaxyl. Steam, solar heating, and crop rotation also have been suggested as alternatives to chemical fumigants. None of these are broad-spectrum control measures, however. If Florida growers cannot use methyl bromide, suitable alternatives need to be developed. Some recent research gives insight concerning possible choices. In studies by Overman (1985) and Overman and Jones (1986), solarization was found to be a useful treatment for tomato, a short-term crop. Studies by Overman et al. (1987) on strawberry (a long-term crop) compared four treatments; a sorghum cover crop either alone or with fumigation (methyl bromide-chloropicrin), and solarization either alone or with fumigation. Except for the sorghum treatment alone, the other 3 treatments produced similar fruit yields. The objective of this study was to evaluate some additional alternatives to methyl bromide in strawberry fruit-production fields.

MATERIALS AND METHODS

The soil in the trial area at GCREC-Dover was a Seffner fine sand (sandy, siliceous, hyperthermic Quartzipammentic Haplumbrepts) and had been in strawberry fruit production for the last 25 years. The soil in the plant beds was fumigated with Vorlex (methyl isothiocyanate + 1,3-dichloropropene) for the first 10 years and then with methyl bromide-chloropicrin for the last 15 years. A sorghum-sudangrass (*S. bicolor* × *S. sudanense*) cover crop was grown each summer and roto-tilled into the soil prior to fumigation. During each fall season, beds were formed, fumigated, and a strawberry fruit-production field established. For this study, a randomized complete block with eleven soil treatments and three replicates per treatment was used. The solarized plant beds were formed on 6 July 1994, and soil fumigation treatments and clear mulch were applied. Broiler manure was used because of the strong ammonia odor present in this manure. All of the clear-mulched plots were treated with Devrinol (N,N-diethyl-2-(1 naphthalenyloxy)-propionamide) at 1.8 kg a.i. ha^{-1} applied to the bed surface prior to clear-mulch application. Vapam (sodium methyldithiocarbamate) was applied to a 122 cm wide swath and plant beds were made using this swath so that Vapam was incorporated into the soil. Soil temperatures were monitored under the clear mulch at the 12.5 cm and 25 cm soil depths in the bed middle from 2 Aug. to 6 Oct. 1994. On 14 Oct., the clear mulch was painted with black paint. On 7 Oct. 1994, additional fumigation treatments were applied to the vacant beds (Table 1) and mulched with black polyethylene (Devrinol was not applied to the black mulched beds). On 14 Oct., 28 strawberry plants each of 'Sweet Charlie' and 'Oso Grande', obtained from the Ghesquiere Nursery in Canada, were set in all beds. Plant beds were 61 cm wide and plots were 415 cm long. Plants were irrigated during the day as needed, until established. Beds were fertilized with a 5-0-6 fertilizer weekly at the rate of 0.2-0.3 kg $ha^{-1}day^{-1}$ of N and K. Plants were sprayed with labelled fungicides to control disease, and predator mites were used to control two-spotted spider mites. Fruit was harvested twice weekly from 3 Jan. to 12 Apr. 1995. Plant vigor (size) was determined on 15 Dec. 1994 and 2 Feb. 1995. Weed control (weeds/plot) was evaluated on 11 Apr. 1995.

RESULTS AND DISCUSSION

Evaluating the effect of treatments on fruiting response without considering mulch color indicated few fruit yield differences (Table 2). The high rate of broiler manure reduced fruit yields throughout the season.

Table 1. Fumigation treatments with clear or black polyethylene mulch.

Clear mulch (solarization)			Black mulch		
Treatment no.	Soil† treatment	Rate per bedded ha	Treatment no.	Soil† treatment	Rate per bedded ha
1	None		7	None	
2	MBR/PIC	224 kg	8	MBR/PIC	224 kg
3	Broiler manure	40 Mg	9	MBR/PIC	448 kg
4	Broiler manure	80 Mg	10	C-17	152 L
5	C-17	76 L	11	Vapam	380 L
6	Vapam	189 L			

†MBR/PIC = Methyl bromide 98% and chloropicrin 2%
C-17 = 1,3,dichloropropene (Telone) 77.9%
Chloropicrin 16.5%
Inert ingredients 5.6%
Vapam = Metham sodium

Table 2. Marketable fruit yields for December, December through February, and the entire season for the 1994-95 solarization study. Average of both cultivars.

Soil treatment	Rate ha^{-1}	Dec. fruit yield	Dec. through Feb. fruit yield	Total yield
		kg ha^{-1}		
1. None + solarization	0	3170a†	10 725a	33 955a
2. MBR/PIC + solarization	224 kg	3304a	10 868a	32 438a
3. Chicken manure + solarization	40 Mt	2879a	9153a	31 639a
4. Chicken manure + solarization	80 Mt	1521b	6024b	17 977b
5. C-17 + solarization	76 L	3143a	9655a	34 035a
6. Vapam + solarization	189 L	3295a	11 408a	32 967a
7. None	0	2363ab	9388a	28 497a
8. MBR/PIC	224 kg	3237a	10 778a	33 059a
9. MBR/PIC	448 kg	3291a	9737a	31 312a
10. C-17	152 L	2700a	10 315a	33 702a
11. Vapam	380 L	3122a	10 459a	31 966a

December fumigant × cultivar fruit yield interactions		Fruit yield of cultivars through February, and total yield	
Fumigant 1 SC‡ = 3685a	Oso = 2656b	SC = 11 889a	27 814b
Fumigant 5 SC = 3584a	Oso = 2591b	Oso = 7840b	34 411a

†Means in the same column followed by a common letter are not different ($P < 0.05$) by Duncan's multiple range test.
‡SC = Sweet Charlie, Oso = Oso Grande

This was expected, because an average of 10 of the 28 plants $plot^{-1}$ were lost. The black mulch treatment without an accompanying soil treatment gave somewhat diminished December fruit yields. When fruit yields were evaluated within a given mulch color (Table 3), additional differences were apparent in the December through February yields for clear mulch. For treatments using black mulch there were no significant yield differences through February, however. Total yields were lowest with the treatment receiving black mulch and no accompanying soil treatment. With clear plastic mulch the 36 Mg ha^{-1} (18 ton $acre^{-1}$) broiler manure treatment reduced fruit yields through February. Total yield and seasonal average fruit weight were also reduced for the

Table 3. Marketable fruit yields through February and for the season as affected by mulch color. Average for both cultivars.

Soil treatment	Rate ha^{-1}	Dec. thru Feb. yield (kg ha^{-1})	Total fruit yield results: Fruit yield (kg ha^{-1})	Avg. fruit wt (g $fruit^{-1}$)	% MKT fruit
			Clear mulch		
1. None + solarization	0	10 725ab†	33 955a	17.28a	78.96a
2. MBR/PIC + solarization	224 kg	16 868ab	32 438a	17.31a	81.60a
3. Chicken manure + solarization	40 Mt	9153b	31 639a	16.97a	81.65a
4. Chicken manure + solarization	80 Mt	6024c	17 977b	15.87b	81.69a
5. C-17 + solarization	76 L	9655ab	34 035a	17.12a	80.14a
6. Vapam + solarization	189 L	11 408a	32 967a	16.97a	79.40a
			Average for cultivars‡		
Sweet Charlie SC		11 834a	27 449b	16.91a	77.73b
Oso Grande Oso		7780b	33 553a	16.93a	83.41a
			Black mulch		
7. None	0	9388a†	28 497b	16.85a	82.87a
8. MBR/PIC	224 kg	10 778a	33 059ab	16.85a	82.23a
9. MBR/PIC	448 kg	9737a	31 312ab	16.90a	80.98a
10. C-17	152 L	10 315a	33 702a	17.45a	81.20a
11. Vapam	380 L	10 459a	31 966ab	17.39a	80.22a
			Average for Cultivars		
Sweet Charlie		11 954a	28 276b	16.58b	77.49b
Oso Grande		8317b	35 440a	17.06a	85.51a

†Means in the same column within a mulch color followed by a common letter are not different ($P < 0.05$) by Duncan's multiple range test. There were no significant soil treatment × cultivar interactions within a mulch color.
‡ Cultivar means averaged over soil treatments and three replications.

Table 4. Effect of soil fumigant/solarization treatment on strawberry plant vigor (plant size) 15 Dec. 1994 and 2 Feb. 1995.

		Plant vigor (%)			
		Sweet Charlie		Oso Grande	
Soil treatment	Rate ha^{-1}	15 Dec. 94	2 Feb. 95	15 Dec. 94	2 Feb. 95
1. None + solarization	0	88a†	87a	82a	90a
2. MBR/PIC + solarization	224 kg	78ab	78a	88a	82a
3. Chicken manure + solarization	40 Mt	63bc	77a	73a	83a
4. Chicken manure + solarization	80 Mt	53c	53b	58a	57b
5. C-17 + solarization	76 L	88a	90a	83a	92b
6. Vapam + solarization	189 L	88a	87a	87a	90a
7. None	0	70a	75a	70a	83a
8. MBR/PIC	224 kg	77a	78a	80a	82a
9. MBR/PIC	448 kg	87a	87a	83a	92a
10. C-17	152 L	70a	78a	88a	90a
11. Vapam	380 L	77a	83a	95a	93a

†Means within columns followed by the same letter are not significantly different ($P < 0.05$) as determined by Duncan's new multiple range test.

72 Mg ha^{-1} (36 ton acre^{-1}) broiler manure treatment. Fruit yields of 'Sweet Charlie' were greater than those of 'Oso Grande' for the season through February, though total fruit yields were higher with 'Oso Grande'. The average fruit weight was highest with 'Oso Grande' when using black mulch and the percent marketable fruit was highest with 'Oso Grande' for either mulch color. Plants in treatments 3 and 4 had a somewhat lower plant vigor with the 'Sweet Charlie' cultivar on 15 Dec. 1994, but only the 'Oso Grande' in treatment 4 had lower plant vigor on 2 Feb. 1995 (Table 4). Numbers of weeds per plot (ranging from 1.7 to 6.3) were not significantly different because of soil treatments (Table 5).

The soil temperature data (Table 6) indicated that, at the 12.5 cm (5 inch) depth, the maximum soil temperature was above 38°C (100°F) during most days. The weather was cloudy with frequent rain (Table 7), which probably lowered observed soil temperatures. There were, however, several days of 49°C or above at the 12.5 cm (5 inch) soil depth, as noted.

Results of this study gave few significant differences among treatments. Treatment number 9 is the standard grower method and gave good results, but results were not significantly greater than for most other treatments. One reason for the lack of significance between the standard and other treatments may be because the soil in the study area had been treated with the standard treatment for the past 15 years. Nematodes were not found in soil samples taken in March around the roots of plants in treatments 1 and 7. At the end of the fruiting season, several smaller plants in plots of the C replicate were checked for nematodes. Only two plants were shown to have them, with one plant coming from treatment 7 and the other from treatment 8. Most inspected roots of the small plants were dark brown. The larger plants had both new white roots and some roots which were dark brown. *Fusarium* and *Rhizoctonia* were found on the brown roots of several of the small plants. The soil in replicate C had somewhat higher soil moisture levels than the other 2 replicates.

The loss of plants in the broiler manure treatments was likely because of high salinity levels in areas of the bed receiving excess manure. The manure was bulky and difficult to separate into small pieces, resulting in

Table 5. Effect of soil fumigant/solarization treatment on weed control under polyethylene mulch, 11 Apr. 1995.

Soil treatment	Rate ha^{-1}	Total number of weeds per plot
1. None + solarization	0	4.0a†
2. MBR/PIC + solarization	224 kg	3.3a
3. Chicken manure + solarization	40 Mt	1.7a
4. Chicken manure + solarization	80 Mt	6.3a
5. C-17 + solarization	76 L	3.0a
6. Vapam + solarization	189 L	3.0a
7. None	0	5.3a
8. MBR/PIC	224 kg	3.0a
9. MBR/PIC	448 kg	5.0a
10. C-17	152 L	2.7a
11. Vapam	380 L	3.7a

†Means within columns followed by the same letter are not significantly different ($P < 0.05$) as determined by Duncan's new multiple range test.

Table 6. Monthly average soil temperatures at the center of a clear-mulched plant bed for fumigant treatment 1 from 2 Aug. to 6 Oct. 1994.

Soil temperature (°C)					
	12.5 cm soil depth			25 cm soil depth	
Month	Average high	High range	Month	Average high	High range
Aug.	47	34-49†	Aug.	43	34-47
Sept.	43	26-49	Sept.	39	32-46
Oct.	40	28-43	Oct.	37	34-39
	Average low	Low range		Average low	Low range
Aug.	31	27-36	Aug.	34	29-38
Sept.	27	26-32	Sept.	32	28-35
Oct.	28	28-29	Oct.	31	30-32

†50°C was the highest temperature our recorder could chart.

Table 7. Weather data for GCREC-Dover from 2 Aug. to 6 Oct. 1994.

Month	Monthly average air temperature (°C)			Rainfall (mm)
	Maximum	Minimum	Range	
Aug.	32	22	20-33	307
Sept.	31	22	19-33	252
Oct.	30	21	18-31	30

uneven distribution. Manure from a well-managed layer operation may be a better alternative, since this manure is usually dry and the particle size is quite small. However, layer manure also generally has high levels of calcium, which could increase soil pH to high levels if used for several years.

Similar studies in the future should probably be conducted on soils which have received little methyl bromide-chloropicrin fumigation during the 2 or 3 years prior to the study. If methyl bromide cannot be applied to soils in the future, nematodes and soil-borne diseases may become more than the relatively minor problems they are at present in production beds. The use of soils already contaminated with nematodes and disease spores would be a more realistic test of the nematicides and fumigants (solar or chemical) which will remain available after methyl bromide is banned.

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The Containerized Gradient Concept—Potential For Undiminishing Nutritional Stability

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ABSTRACT

Containers have been designed to maintain the parameters of a gradient-oriented nutritional procedure that is currently being used for field-grown horticultural crops in Florida. A surface source of N-K or N-P-K in conjunction with a built-in seepage source of water moves by diffusion to equilibrate with the less soluble nutrients in the media (0.08 m^3 of soil or potting mix). The total concept is designed to synchronize nutrient/water inputs with rate of removal by the crop. Even with the higher plant/soil ratio (about 10 times that in the field), the gradient procedure provides long-term nutritional stability in the media solution that creates the potential for advances in productivity. Tomato yields of 6 to 10 kg $plant^{-1}$ with outstanding quality are a reflection of this nutritionally stable rhizosphere. The gradient, in contrast to conventional or hydroponic procedures, is maintained with minimal management. This is true regardless of the soil-plant-season. With the Earth Box™—a gardener's version of the containerized gradient concept—all of the nutrients for one or more crops are placed in the container, the water requirement is limited to that used for transpiration (there is no leaching), and minimal management is required to maintain the recommended parameters. The potential of the concept as a worldwide sustainable production system is currently being evaluated—for the farmer as well as for the home gardener.

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The gradient concept was initiated and evaluated during the 1960's as the nutritional component for a field-oriented full-bed mulch system of production (Geraldson 1963, 1970). The basic components are a soluble source of nitrogen (N) and potassium (K) on the soil bed surface in conjunction with a constant water table. The N and K move by diffusion to the root and equilibrate concurrently with the less-soluble nutrients in the soil to maintain a predictable range of decreasing ionic concentrations with associated decreases in the ratio of N and K to total ions in the soil solution. The full-bed mulch minimizes the effects of evaporation and rainfall as physical forces that can alter the ionic composition of the soil solution. The total concept is designed to synchronize the rates of nutrient/water input with those of crop removal, and thus provide long-term nutritional stability.

Nutrients in the soil move by diffusion, which is synchronized with removal, or move by mass flow with the water, which is *not* synchronized with removal. By eliminating in-bed N-K (conventional procedure) and using on-bed N-K (gradient procedure), it is possible to maintain a continuing nutritional stability in the soil solution.

When conventional nutritional procedures are exposed to variations in soil-plant-season combinations, nutritional stability in the soil solution can be weakened or destroyed. In the transition to more intensive production systems, conventional nutritional procedures often cannot maintain the nutritional stability required for continuing advances in productivity, whereas the gradient procedure sustains that stability.

Tomato yields from experimental field plots using a gradient-oriented procedure averaged 75 to 80 t ha^{-1} for 9 successive crop seasons (1964-68) compared to the commercial average of 16 t ha^{-1} from an equivalent (unmulched) area (Geraldson 1970). In the transition to a full-bed mulch system during the 1970's, average commercial yields more than doubled (Bredahl et al., 1983; Van Sickle et al., 1992). In shifting to the full-bed mulch procedure, the recommendations required to sustain the gradient were often diluted with conventional procedure, because innovation that changes the prevailing procedure is not readily accepted and often is fought with great vigor because it compromises the former investment. The full potential of the gradient generally cannot be attained with alternative procedure that weakens or destroys the integrity of the concept.

In order to further evaluate the potential of the gradient concept, a surface-applied microsource of water in conjunction with a separate surface source of N and K were used to evaluate a lateral-oriented gradient (Geraldson 1973). Tomatoes were grown in containers - wooden boxes that held 0.4 m^3 of soil that ranged in type from sandy to organic (peat). The maximum yield was about 8 kg $plant^{-1}$ (four plants box^{-1}) regardless of the soil type. Mass flow of nutrients was minimized but, without a water reservoir, variations in moisture jeopardized the nutritional stability.

Current evaluations using a containerized gradient procedure strongly support the validity of the gradient as a nutritional paradigm that can be used to enhance productivity.

MATERIALS AND METHODS

The Earth Box™ (Fig. 1), made of recycled plastic (manufactured by Laminations, Inc., P.O. Box 2021, Scranton, PA 18509) holds 0.08 m^3 of media (soil or potting mix) with a water reservoir that holds 8.4 L and is designed to maintain a nutritional gradient (Geraldson et al., 1995). The media is supported on a grid above the water reservoir, with an overflow hole that maintains a minimal 1.25 cm air space between the media and a fluctuating water table. The two rear corners of the grid are cut away, allowing the media to extend into the water reservoir. This provides a seepage route for water.

The N-K or N-P-K is banded at the surface and dolomite + micro-nutrients ± phosphorus is mixed in the top 2 to 5 cm of media. Whether grown in the field or a container, a given yield requires a proportionate quantity of nutrients. The quantities of N, K, Ca, Mg and P required by tomatoes (per ha or per plant), and the quantities of selected source materials to supply those requirements, are presented in Table 1.

Fertilizers—300 g $plant^{-1}$ of an 18-0-25 material and 40 g of 0-20-0 material—would provide the N, P and K for a tomato yield of 9 kg $plant^{-1}$ (Table 1). Dolomite—

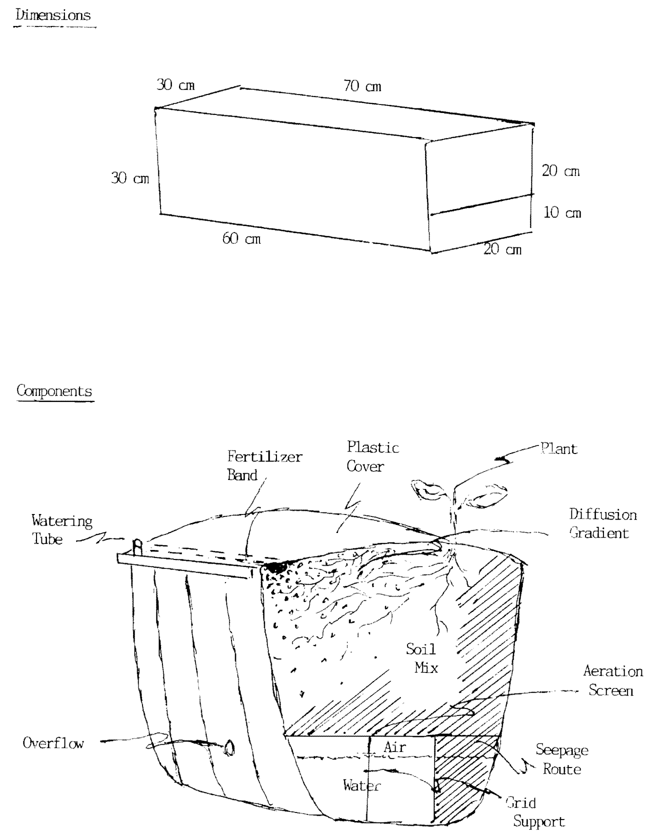

Fig. 1. The Earth Box™.

450 g, which is in excess of the required Ca and Mg—equilibrates with the more soluble nutrients to provide a range of nutrient concentrations and ratios that favors maximum productivity.

Transplants for both fall (Aug.-Nov.) and spring (Feb.-May) were used for all crops. Tomatoes were harvested vine ripe, primarily during Nov. or May. The total weight $plant^{-1}$ (2 plants $container^{-1}$) and the average fruit size from determinate cultivars (Table 2) were used to evaluate the potential of the concept to maintain nutritional stability over time. With the emphasis on diffusion, nutrition as a science can advance beyond the conventional trial-and-error procedure, providing a predictable gradient/plant-oriented stability.

Table 1. The nitrogen, potassium, calcium, magnesium and phosphorus required for a 45 t ha^{-1} tomato yield, or 9 kg $plant^{-1}$, and the quantity of selected sources to supply that requirement (Geraldson, 1963).

	Required			Supply	
	45 t ha^{-1}	9 kg $plant^{-1}$	Source†	45 t ha^{-1}	9 kg $plant^{-1}$
N	245 kg	49 g	18-0-25	1356 kg	268 g
K	285	56	18-0-25	1356	268
Ca	112	22	Dolomite	522	104
Mg	44	8.1	Dolomite	373	72
P	46	8.2	0-20-0	478	113

†N-P_2O_5-K_2O; dolomite + micronutrients (Mn, Zn, Cu, Fe, B and Mo).

Table 2. Tomato production using a containerized gradient procedure for 3 crop seasons (kg plant^{-1}, g fruit^{-1})†.

	Season					
	1990		1991		1992	
Cultivar	kg plant^{-1}	g fruit^{-1}	kg plant^{-1}	g fruit^{-1}	kg plant^{-1}	g fruit^{-1}
BHN-22	6.1	207	7.0	238	7.5	221
Sunny	6.9	167	6.8	189	8.6	172
Solar Set	6.7	176	—	—	—	—

†Average of 3 reps (2 plants container^{-1}).

Because of potential water restrictions in Florida, microirrigation has become a recommended procedure—one that concurrently has increased costs and requires intensive management to even approach a productivity equivalent to the potential of the gradient in subirrigated systems. Fertigation (providing N-K in the irrigation water) as a recommended component and a mass flow source also modifies the gradient concept. In contrast, the containerized gradient procedure has the potential to become a sustainable production system—one that will benefit society and allow the farmer to competitively (i.e., economically) excel. It is also a technique of benefit to the gardener and individual home owner.

RESULTS AND DISCUSSION

Containers were designed to provide the recommended parameters for a gradient-oriented nutritional procedure. Even with the limited capacity of the container, the outstanding yield and quality of tomatoes from the containerized gradient system is a reflection of long-term nutritional stability; 13 to 20 kg container^{-1} with 2 plants container^{-1} (Table 2), with a quality that reflects the continuing vigor of nutritionally healthy plants. Productivity (fruit set, size and overall quality) of conventional tomato crops diminishes as the season progresses, which strongly affects marketability. The concentrated fruit set of determinate tomato cultivars using the nutritional stability of a gradient-oriented procedure has the potential for continued fruit set while, at the same time, maintaining size and quality as the season progresses. It is felt that maximum productivity levels have not yet been attained. Support parameters, and especially temperature, also require further definition and evaluation.

Conventionally containerized production using soil, potting mix or rock wool in pots or bags with nutritionally stable, hydroponically orientated formulations (Van Noordwijk 1990), requires intensive management (periodic adjustment along with leaching or replacing the soil or hydroponic solution to maintain or restore nutritional stability). The cost, required management and vulnerability of this procedure has limited its potential.

With the gradient procedure all of the nutrients for one or more crops are placed in the container initially. Water required is only that used for transpiration; there is no leaching, and management is reduced to simple maintenance of a water table plus necessary pest-control procedures. Many vegetable crops, strawberries and flowers have been grown in the Earth Box™. Climate-wise, rainfall is not a problem; with the enclosed system, leaching and evaporation are eliminated as contributing variables. Effects of temperature variations are still being evaluated.

With the gradient concept as the dominant source of nutrients, nutritional research approaches that of an exact science, because the gradient composition is maintained by the chemical processes of diffusion and equilibration—providing long-term nutritional stability regardless of the soil-plant-season and whether the crop is grown in the field or a container.

The Earth Box™ is primarily for the home gardener, but a commercial version is being evaluated for a containerized field operation. That was, and remains, the overall goal of this research effort.

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FLATWOODS—A Distributed Hydrologic Simulation Model for Florida Pine Flatwoods

G. Sun*, H. Riekerk, and N. B. Comerford

ABSTRACT

Simulation models are especially useful in the study of forest hydrology, which is more complex than many other hydrological systems. Most of the existing hydrologic models developed for hilly regions are not readily applicable to flatwoods ecosystems characterized by flat topography, a high and dynamic groundwater table in poorly drained soils, and heterogenous landscape of cypress wetlands and pine uplands. The present FLATWOODS model was adapted from the COASTAL model to study the effects of silvicultural practices on hydrological processes in Florida flatwoods ecosystems. FLATWOODS is classified as a distributed, watershed-scale, physically based, integrated wetland-upland, dynamic model. The model consists of three separate submodels, simulating evapotranspiration, unsaturated soil water flow and the saturated groundwater-flow processes. The model has been calibrated and verified with field measurements of groundwater table elevation and daily runoff collected from two different pine flatwoods experimental sites. Although the model under-predicts high flow rates, simulation results matched most of the observed data well and suggest the promise of the model for water management in flatwoods ecosystems.

Studies on the hydrologic impact of silvicultural management practices in Florida flatwoods have been conducted mostly by the Intensive Management Practices Center (IMPAC) at the University of Florida over the past two decades (Neary et al., 1982; Riekerk et al., 1979; Rodriguez, 1981; Riekerk, 1989). Accumulated data indicate that clear-cutting of forests may cause 150% increase in runoff and 30-100 cm rise of groundwater table in the first year of post-treatment. Many questions remain, such as:

a. To what extent do forest management practices affect hydrology under different conditions (e.g., magnitude of disturbance, weather regime, drainage, fertilization)?
b. What are the processes governing the change of hydrology due to silvicultural practices?
c. How long do the impacts last during a forest rotation cycle?
d. What are the quantitative criteria for Best Management Practices (BMP's) to reduce silvicultural impacts on this heterogeneous landscape?

Hydrologic models have been widely used since the 1960's in water resources management (Fleming, 1975). With the advancement of digital computer technology, computer modeling methods have proven to be especially useful in the study of forest hydrology because:

a. Hydrologic processes in forested watersheds are complex and interrelated, thus being difficult to quantify separately by field experiments.
b. Forests are normally located in remote areas, so direct measurements of real data are often expensive, if at all possible.
c. A distributed forest hydrologic model can be used to predict the long-term effects of various forest management practices, and to compare the effectiveness of different BMP's.
d. In general, reliable computer simulation techniques are more cost-effective as compared to field experimentation.

It is financially prohibitive to address questions of the above types by traditional experimental approaches. Modern computer simulation techniques provide an alternative means for scientists to solve problems (Fleming, 1975). Although numerous forest hydrologic models currently exist, most of them cannot be directly applied to Florida's relatively flat terrain, and have difficulty handling forested wetland-upland systems (Capece, 1984; Sun, 1985; Heatwole, 1986; Tremwel and Campbell, 1992).

A simulation effort was made by Guo (1989) to test applicability of the simulator VSAS2 for a pine flatwoods watershed in the Bradford Forest near Gainesville, FL for the prediction of stormflow. Simulation of five storm events showed that the original simulator significantly overestimated peaks of the stormflow hydrographs. Pond storage in this flat and complex landscape was suggested to play a significant role in runoff generation. Some models specifically developed for simulating high water table conditions in agricultural fields, such as CREAMS-WT (Heatwole, 1986), DRAINMOD (Skaggs, 1984), and FHANTM (Tremwel and Campbell, 1992), are applicable to horizontally relatively homogenous fields. How these models perform in spatially heterogeneous forested flatwoods is not known. Models developed to study wetland hydrology often include only the wetland itself, without the surrounding upland components (Scarlatos and Tisdale, 1989; Kadlec, 1993). Current ecological models to study water and nutrient or carbon fluxes in pine flatwoods employ a lumped approach, and place significant emphasis on the vegetative components with various simplification of the soil components and water pathways in such ecosystems (Golkin and Ewel, 1984). The COASTAL model (Sun, 1985) was selected as the basis to develop the present model, because the former has the basic structure of a distributed watershed-scale model. Advantages and deficiencies are discussed in detail in Sun (1995).

The Florida flatwoods landscape includes a mosaic of cypress wetlands and forest uplands in different age classes, so the hydrology of flatwoods is inherently com-

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plex. Examples include the slight spatial changes in topographic elevation that cause significant changes in the water regime, and obstructive soil layering because of spodic and argillic horizons in the soil profile. The heterogeneous vegetation cover of wetlands and uplands, and associated phenology, further complicate the interactions between surface water and groundwater. Preferential water pathways due to the complex geologic formation of flatwoods in this system have been neither well documented nor understood (Crownover et al., 1995). A functional distributed flatwoods forest hydrologic model is needed to study the hydrologic processes of wetland/upland systems and to provide a tool for water management in this landscape. This paper introduces the FLATWOODS model structure, formulation, and model inputs and outputs. Model calibration and verification results from two research sites near Gainesville, FL, have been presented to demonstrate the model's capability to simulate daily groundwater table fluctuation and runoff. More detailed information about model development and mathematical equations can be found in a dissertation by Sun (1995).

STRUCTURE OF FLATWOODS MODEL

This model imposes a numerical grid over the entire wetland-upland flatwoods system to distribute the heterogeneous watershed into different, but internally homogeneous, rectangular cells (Fig. 1). The physical properties of each cell are assumed to be uniform laterally for each soil layer, but non-uniform vertically because of differing soil layers. Each cell becomes a modeling unit containing mathematical equations describing its physical properties. In practice, spatial data for forest lands are rarely available at high resolution with the exception of some readily available parameters such as surface elevation, vegetation and soil types (wetlands vs. uplands), etc. The model consists of three major submodels, each simulating portions of the hydrologic processes using a daily time step (Fig. 2).

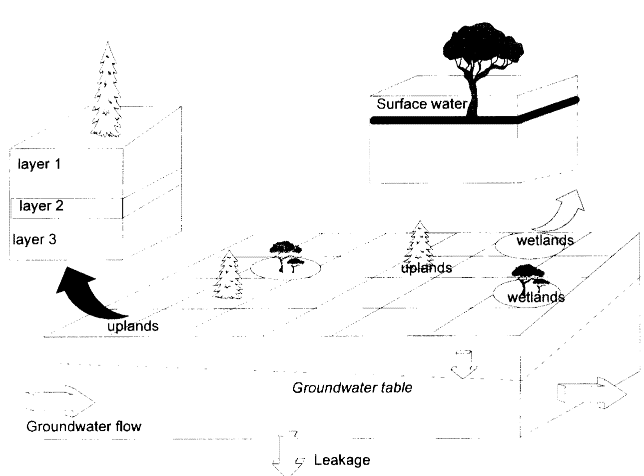

Fig. 1. Grid structure of the FLATWOODS model.

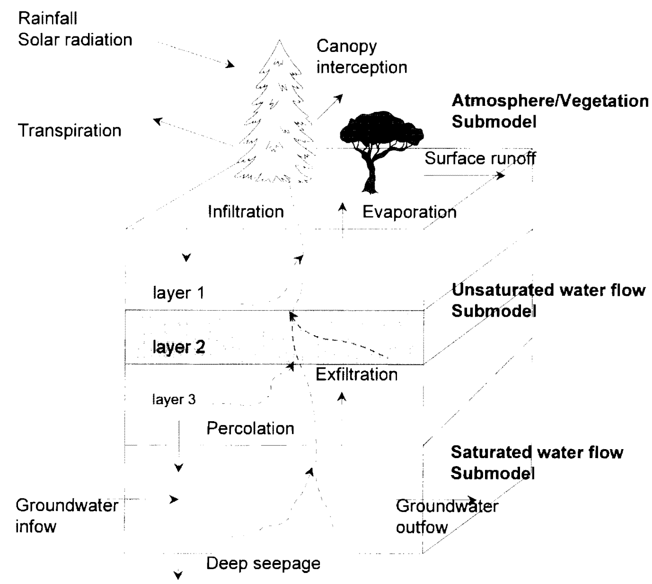

Fig. 2. Hydrologic components in the FLATWOODS model.

Evapotranspiration Submodel

Evapotranspiration (ET) is a highly significant part of the water balance of flatwoods. Driving forces of the hydrologic system are climatic variables including rainfall and air temperature (influencing ET). Daily rainfall and temperature data needed as model inputs for climatic variables are available from actual field recordings or from local weather stations. The ET submodel has three components including a rainfall interception component (I_p) for forest canopies, evaporation from soil/water surfaces, and transpiration through plant stomata. Rainfall interception depends on daily rainfall, leaf area index (LAI) and available canopy interception reflecting relative storage or dryness of the forest canopies. The Penman-Monteith equation has been regarded as the most accurate estimation for potential evapotranspiration (PET), an index of the maximum water loss for given atmospheric and land-cover conditions. This equation, however, needs several climatic variables that are not available for typical research sites. Consequently, the method of Hamon (1963) was adopted to estimate PET, with only daily temperature as a requirement. Evaporation of intercepted water on forest canopies is assigned as first priority on ET demand. Residual potential evapotranspiration (RET) is treated as the difference between PET and evaporation from plant surfaces (intercepted rainfall on canopies). Actual evaporation (AE) from soil/water surfaces is in turn assumed to be dependent on atmospheric demand, soil water conditions and forest canopy shading. Actual transpiration (AT), which involves physical and physiological processes, is the most difficult component to model. In the FLATWOODS model, AT from each of the soil layers is assumed to be a function of possible realized transpiration (PRT), soil water conditions, and root density. The concept of PRT is defined as the maximum transpiration that a crop can have for a certain atmospheric condition and LAI. PRT is assumed to be a function of the residual potential evapotranspiration (RET) and stage of plant development, as indicated by LAI and root density.

Unsaturated Water Flow Submodel

Due to the high infiltration rate of sandy soils of the flatwoods landscape, rainfall that is not intercepted by forest canopies infiltrates rapidly into the vadose zone without any overland flow component, provided the groundwater table is not in the immediate vicinity of the soil surface. A maximum of three unsaturated soil layers has been used to simulate vertical subsurface unsaturated water flow. The first layer (0-40 cm) represents the A horizon, where most plant roots reside. The second layer (40-65 cm) represents the spodic horizon (B_h), where soil properties are distinct from the top layer. The third unsaturated layer ranges from the 65-cm depth to the water table. The actual thickness of each layer varies throughout the simulation, depending on water table depth. For example, if the water table reaches to the soil surface, the whole soil profile is saturated and the number of unsaturated soil layers becomes zero; if the water table depth is greater than 40 cm but less than 65 cm, two unsaturated soil layers are stipulated, with the first layer from 0 to 40 cm and the second from 40 cm to the water table level. Drainage representing downward unsaturated water flow from an upper layer to a lower layer is estimated by Darcy's equation, assuming unit total potential gradient. Hence, the drainage rate is approximated as the soil hydraulic conductivity. The upward water flux represents water flow from a lower layer to an upper layer, driven by the water potential gradients induced by ET. This component is calculated in direct proportion to the ET flux of a layer. While evaporation from the soil surface is assumed to take place only from the first layer, plant roots extract water from all three unsaturated layers and from the saturated zone. Soil moisture content is updated via the water balance for each layer. For some areas, such as wetlands, the soil profile may be fully saturated during part or all of the year. Percolation from the bottom of the third layer of the unsaturated zone becomes the input (source) to the underlying saturated subsystem.

Saturated Water Flow Submodel

The base of the unsaturated zone becomes the upper boundary of the saturated zone. The bottom of the saturated zone has been set at the top of a clay layer ≈ 2-3 m deep with a low hydraulic conductivity ($<10^{-3}$ m d^{-1}). Below this flow-restricting clay layer, which may be discontinuous in extent, often lies another intermediate aquifer composed of sands and sandy loams. Vertical flow (leakage) through the bottom of the saturated zone is estimated using an empirical function. Within the saturated zone of this submodel, water moves horizontally from one cell to the surrounding four cells governed by a 2-D groundwater flow model with Dupuit assumptions (Bras, 1990). The two important parameters in the groundwater flow equation, specific yield and hydraulic conductivity, are not constant but vary depending on the position of the water table in the soil profile. The input source for the submodel is water percolation from the unsaturated zone. A sink for the groundwater flow model includes ET extracted from the watertable aquifer, exfiltration (upward flux) from the saturated zone to the unsaturated zone, and/or surface flow from those cells where the water table is above a critical elevation.

Table 1. A list of inputs required to run the FLATWOODS model.

Model Inputs	Variables/Parameters
Climatic data	Daily rainfall; Daily average air temperature; Latitude of the study site; Correction factor for calculating potential evapotranspiration by Hamon's method; Empirical function for rainfall interception.
Watershed configuration	Grid size, width and length, area; Land use type (cypress wetlands, pine upland, harvested wetland, and harvested upland); Topographical elevation and bottom elevation of each cell; The critical elevation of each cell; Boundary condition identifiers: 0 = no flow 1 = variable hydraulic head -1 = constant gradient boundary.
Soil parameters	Soil moisture characteristic curves by Van Genuchten's method; Saturated hydraulic conductivity of each soil layer in each cell; Specific yield of each soil layer in each cell; Relation between soil moisture content and water table level for different soil layers; Empirical parameters used in the ET submodels; Empirical parameters used to calculate surface runoff and deep seepage.
Vegetation parameters	Leaf area index functions for each forest type and their change with time (d); Root density for each forest type in each soil layer (m m^{-3}).
Initial conditions	Hydraulic head (water table elevation) in each cell throughout the watershed at the beginning of a simulation.

MODEL INPUTS AND OUTPUTS

Data input requirements to run the model are listed in Table 1 and outputs from the model are listed in Table 2.

Table 2. A list of outputs from the FLATWOODS model.

Daily water table elevation in each grid cell and its average over the entire watershed;
Daily rainfall interception, evaporation, and transpiration from each cell;
Daily total surface runoff and groundwater flow across the boundaries from the entire watershed;
Daily water drainage (percolation) from the unsaturated zone to the saturated zone;
Daily soil water storage in each soil layer;
Daily deep seepage from the surficial aquifer to the underlying second aquifer;
Statistical analysis of model performance.

Table 3. Data sources for the model calibration and verification.

Research site		Calibration	Verification
Gator Nationals Forest	Pre-treatment	6 Apr. 1992-31 Dec. 1993 Data: Average groundwater table level	1 Jan. 1994-31 May 1994 Data: Average groundwater table level
	Post-treatment	1 Jun. 1994-31 Dec. 1994 Data: Average groundwater table level	1 Jan. 1995-31 May 1995 Data: Average groundwater table level
Bradford Forest		1 Jan. 1978-31 Dec. 1982 Data: Runoff, groundwater table levels from five wells	1 Jan. 1983-31 Dec. 1992 Data: Runoff

MODEL CALIBRATION AND VERIFICATION

The FLATWOODS model was calibrated and verified with hydrologic data collected from two study sites, in the Gator Nationals Forest (GNF) and the Bradford Forest (Table 3). The GNF site is located 15 km north of Gainesville, Alachua County, FL where Plio-Pleistocene terrace deposits of the underlying Hawthorn Formation dominate the geology. Topographical slopes range from 0 to 1.6%. The average annual temperature is 21°C, with a mean monthly low of 14°C in January and a high of 27°C in July. Average annual rainfall is ≈ 1330 mm, with dry periods during the spring and fall seasons. Approximately 35% of this 42-ha site is in cypress swamps with sizes ranging from a few m^2 to more than 5 ha, while the remaining upland areas are in slash pine plantation.

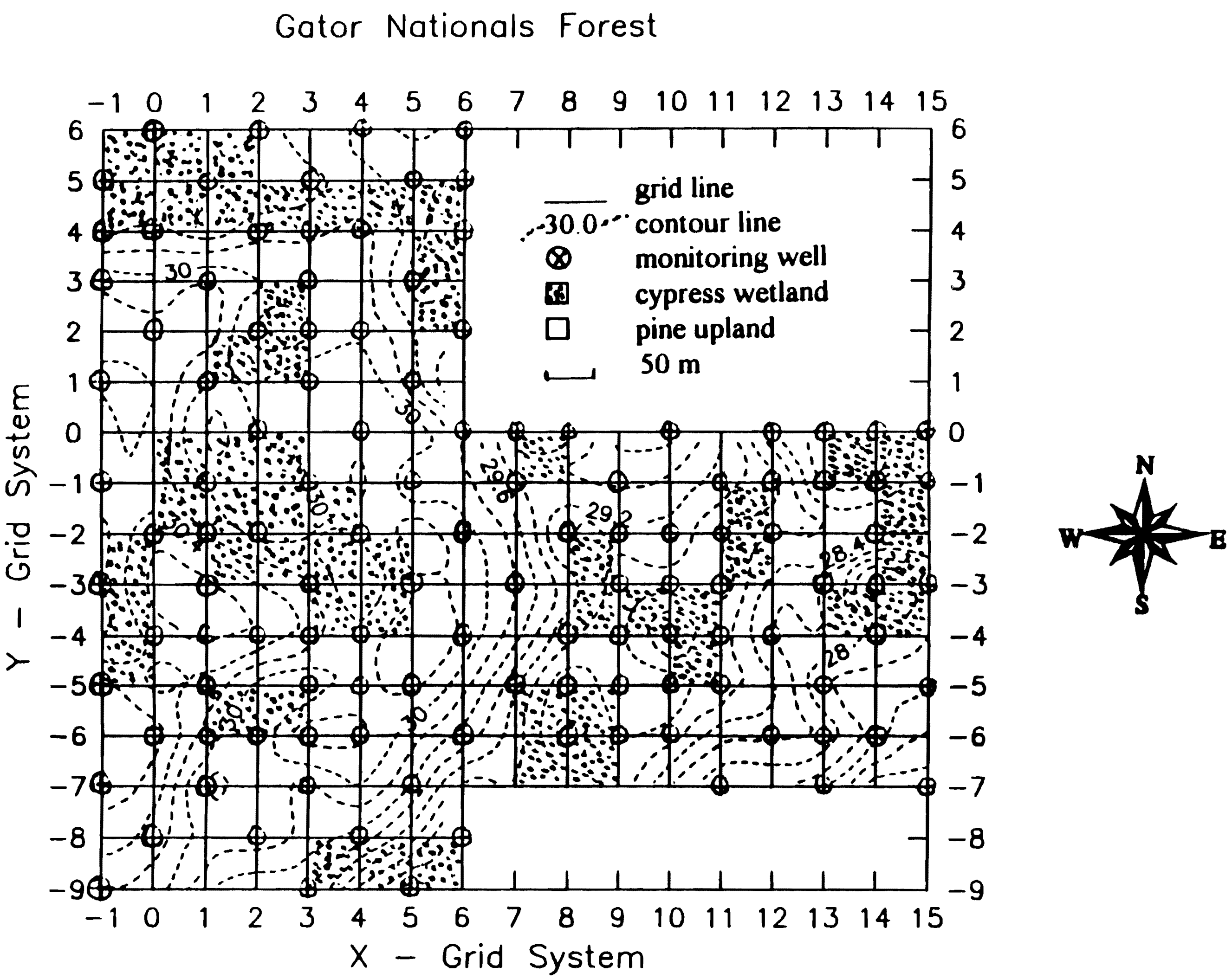

Fig. 3. Physical information for the modeling units of the Gator Nationals Forest site.

The 27-year-old upland plantations were 5th-row thinned in 1986 to a stem density of 500 stems ha^{-1} (Sun et al., 1995). Pond cypress (*Taxodium ascendens* Brongn) dominated the wetland species along with slash pine (*Pinus elliottii* Engelm) and black gum (*Nyssa sylvatica var. biflora* Sarg). The dominant tree canopy in uplands was slash pine with an understory of saw palmetto (*Serenoa repens* Small) and gallberry (*Ilex glabra* Gray) shrubs. A 50 × 50 m grid system was imposed on the entire 42 ha experimental area and each grid point was marked and labeled with a steel post and related to a reference coordinate (0, 0) set at an arbitrary elevation of 30.48 m (100 feet). The actual topographical elevation of the study site was about 47 m above mean sea level. A 1.5-m water table well was installed at every second grid point, and water table data were collected on a biweekly basis from April 1992 through April 1996. The Bradford Forest watershed, with total area of 140 ha, is on commercial forest lands in Bradford County, ≈ 50 km northeast of Gainesville, FL. The geology and the vegetation of this site are similar to those for the GNF site, but over 45% of the experimental watershed is in cypress wetlands.

Although the FLATWOODS model has the potential to use spatially distributed soil and vegetation parameters, it was not realistic to assign completely different values to each cell. Thus, the same values for the leaf area index and soil physical parameters of each soil layer for each land type were used in all cells during the simulation. This gave soil and vegetation cover homogeneity within each layer, with the surface elevation of each cell being interpolated from the topographic map. The bottom elevation of each cell was set as the surface elevation minus a uniform thickness over the entire watershed. Soil parameters for the soil moisture characteristic curves measured by Phillips (1987) at a nearby site were adopted without change.

Gator Nationals Forest (GNF) Site

Pre-treatment

Landuse, topography, and modeling cells are presented in Fig. 3. More than 130 shallow wells (<1.5 m) were installed at the GNF site and the water table level in each well has been measured biweekly starting in April 1992. The arithmetic average of all water table elevations from each measurement was used for model calibration. The model was first calibrated with water table data for the GNF site for a wet year (1992), which had a 170-mm surplus of rainfall compared to normal years. Satisfactory simulation results were obtained for that year. However, when a verification effort was conducted using data collected from a dry year (1993), the model substantially overestimated the water table level using the calibrated parameters of 1992. This problem was probably caused by under-estimation of the depth to the

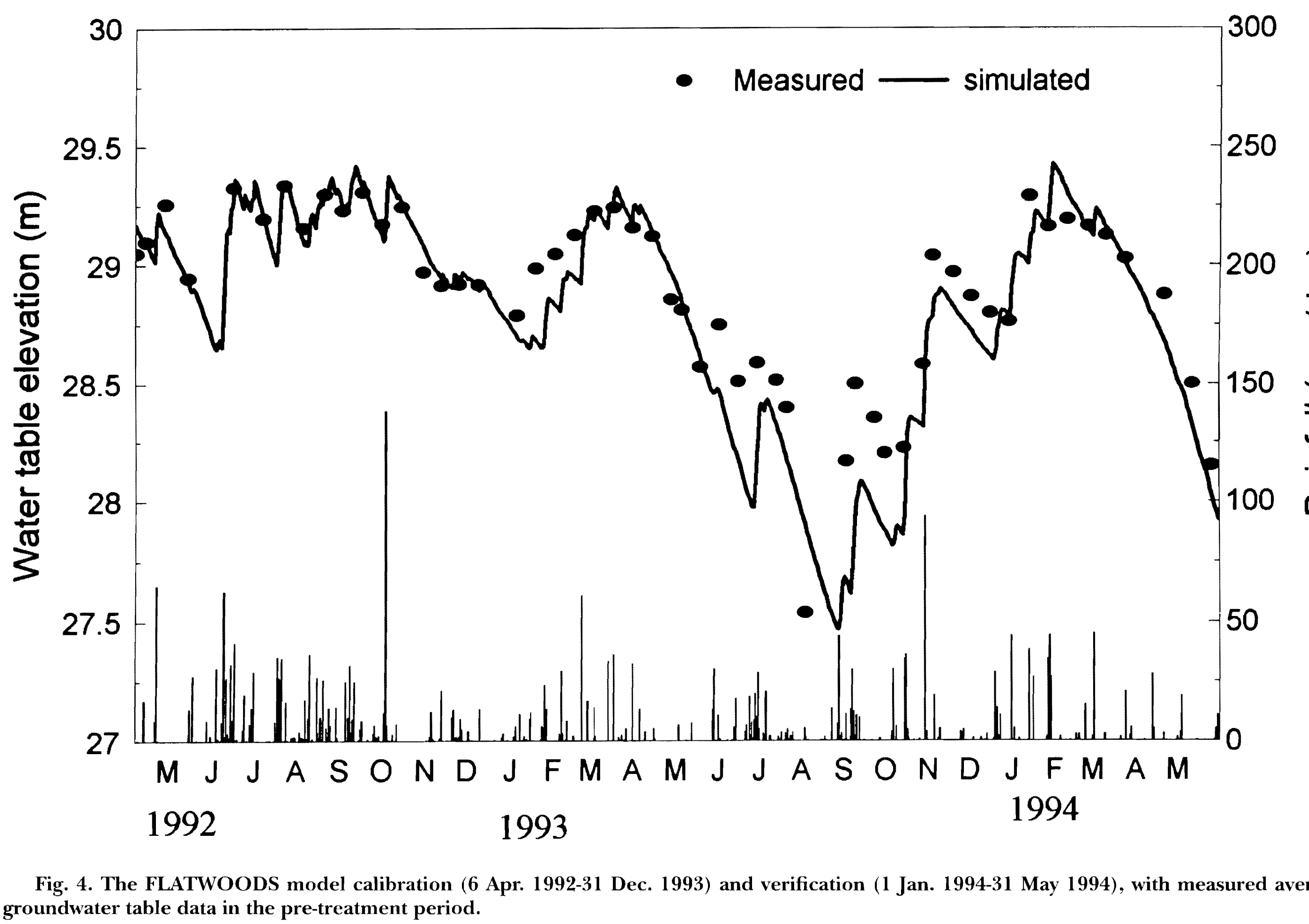

Fig. 4. The FLATWOODS model calibration (6 Apr. 1992-31 Dec. 1993) and verification (1 Jan. 1994-31 May 1994), with measured average groundwater table data in the pre-treatment period.

restricting clay layer. As a result, the restricting depth was changed from 2.0 m to 3.5 m, and a better fit was achieved for 1993 as well. The dry year of 1993 had a rainfall deficit of more than 230 mm compared to a normal year and, consequently, for 6-93% of the observation wells the water table fell below the bottom from May to October. Using both a dry year and a wet year for model calibration enhanced the generality of the model. The calibration results for the pre-treatment period were good and have been presented graphically in Fig. 4. Model verification with data from 1 Jan. 1994 to 31 May 1994 during the pre-treatment period also showed good model performance. The Pearson Correlation Coefficients were 0.91 and 0.96 for the calibration period and the verification period, respectively.

Post-treatment

The harvesting treatments were imposed from 5 Apr. to 31 May 1994, followed by double bedding during the fall of 1994. The southeast block was totally clear-cut, including the cypress wetlands, but only the wetlands were clear-cut in the northwest block of the research area. The harvested upland areas were planted with slash pine seedlings in January 1995 and the cypress wetlands left alone for natural regeneration. The most significant effect of the forest harvesting on model parameters obviously was the reduction in leaf area index. The leaf area index was assumed to be reduced to 0.5 for harvested wetlands and to 0.1 for harvested uplands. Soil structure of the first layer also might have been altered due to compaction by mechanical operations, but the change presumably was minor. Under these assumptions, the model was verified with post-treatment data from 1 June 1994 to 31 May 1995. The model substantially over-predicted the groundwater table elevation during the post-treatment period. Discrepancies were possibly caused by the fact that: (1) the evapotranspiration algorithms did not adequately describe the physical evaporation processes of the harvested areas; and (2) the management practices including bedding probably changed the parameters for the soil moisture (porosity) and surface-flow routing procedures. The model had to be recalibrated in order to determine the extent of changes in the affected parameters due to site disturbance. The model was calibrated again using post-treatment data collected during June 1-Dec. 31 1994 (Fig. 5). Pearson Correlation Coefficients were 0.88 and 0.82 for the model calibration and verification periods, respectively. The simulation results were satisfactory.

Bradford Forest Site

The watershed with a 50-year old forest at the Bradford Forest site was left undisturbed by the IMPAC study

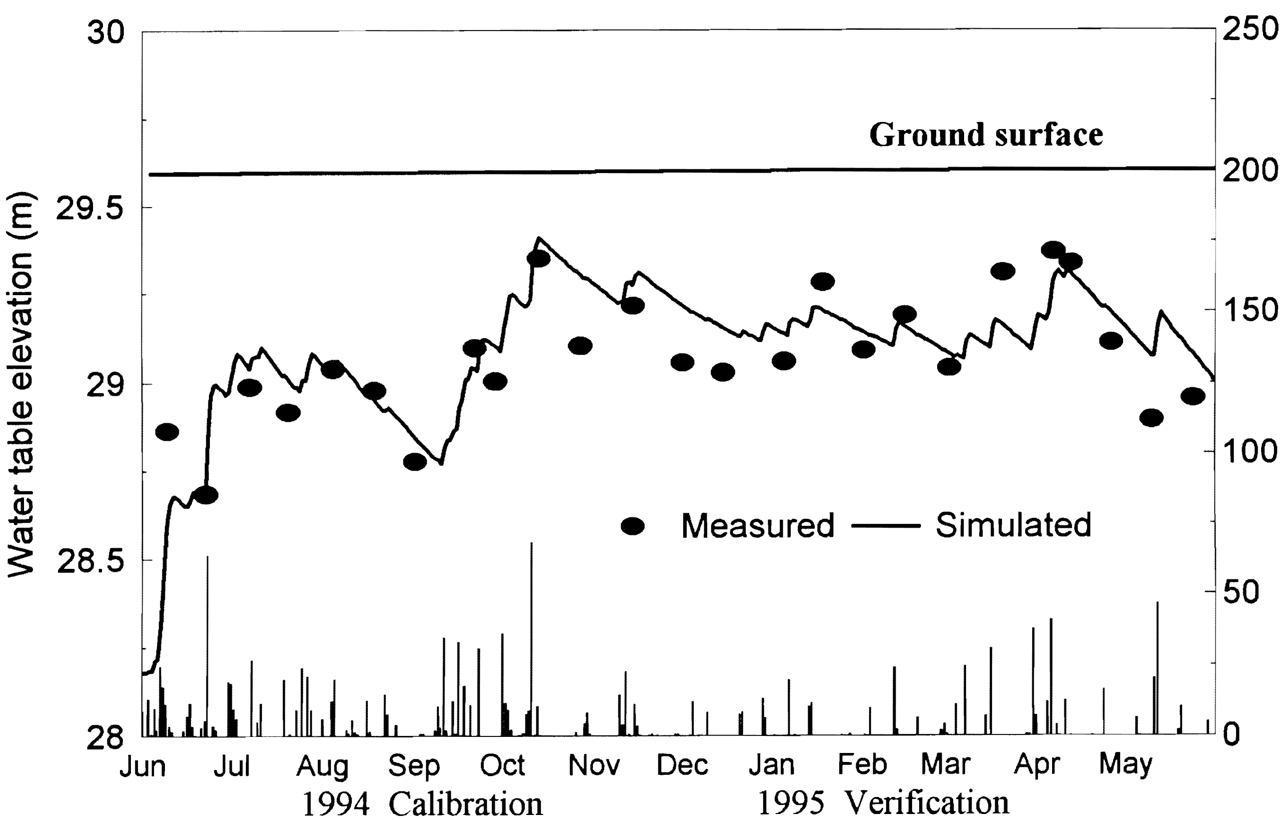

Fig. 5. Simulated and measured average groundwater tables during the calibration (1 Jun.-31 Dec. 1994) and verification (1 Jan.-31 May 1995) periods under post-treatment conditions at the Gator Nationals Forest site.

(Riekerk, 1989) and had a 17-year record of runoff data (1978-1995). However, groundwater table data were discontinuous, with only some spatially distributed data during the first few years. Physical information for each modeling cell at this site is presented in Fig. 6. The FLATWOODS model was calibrated with runoff data for the first five years (1978-1982). The year 1978 was a wet year (1453 mm rainfall), while 1981 was a dry year (916 mm rainfall). The simulated average groundwater table was compared to the recorded groundwater table levels in five shallow wells (Fig. 7a and 7b). Excluding the exceptionally dry year 1981 (Fig. 8), an average Pearson Correlation Coefficient of 0.84 was obtained. The model was further verified with measured runoff data from 1983 to 1992 following the 5-year calibration period (Fig. 9). For ten years of simulation, the model showed encouraging predictability and stability as demonstrated by the high Pearson Correlation Coefficients (0.81-0.89) for most of the years. However, the model could not predict extremely high flows very accurately, causing underprediction of runoff in wet years (1983 and 1992). Two reasons have been hypothesized: (1) the boundary and outlet ditches in this artificially created watershed may generate higher peak flows during the wet seasons, especially in extreme years (Iritz et al., 1994); and (2) the FLATWOODS model uses a single runoff/watertable level relationship independent of time to predict runoff, with no cell-by-cell surface flow routing procedures having been introduced. The assumption made for the runoff-groundwater table relationship seemed effective, since the model could also fit periods of low flow reasonably well during the two-year drought period of 1989-1990.

CONCLUSIONS

The new FLATWOODS model may be classified as a distributed, watershed-scale, physically based, integrated wetland-upland, dynamic model. This forest hydrological simulation model provides an alternate tool to investigate the hydrology for pine flatwoods and can be used by forest managers to evaluate the potential hydrologic effects of different silvicultural practices. As with any other existing watershed-scale hydrological model, performance is heavily dependent on testing with measured data. However, spatially distributed field measurements are rarely available and sufficient for model verification. In this study, daily runoff data and groundwater table data were not collected from the same controlled watershed. For a watershed-scale model like FLATWOODS, uncertainty will remain for model performance until spatially distributed hydrologic variables including evapotranspiration, runoff and groundwater table depth can be evaluated experimentally. Computer simulation models cannot replace field experimentation, but rather serve as a complementary means to achieve the same goals.

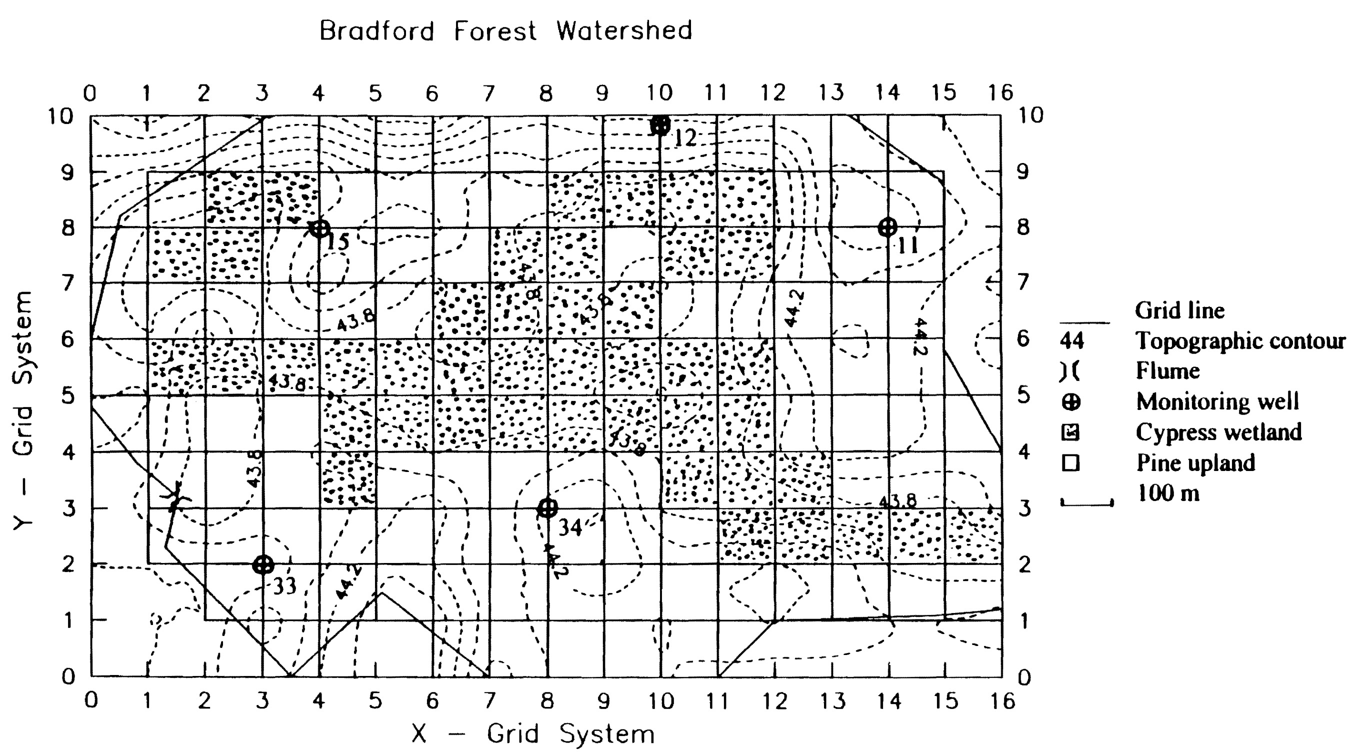

Fig. 6. Physical information for the modeling units of the Bradford Forest site.

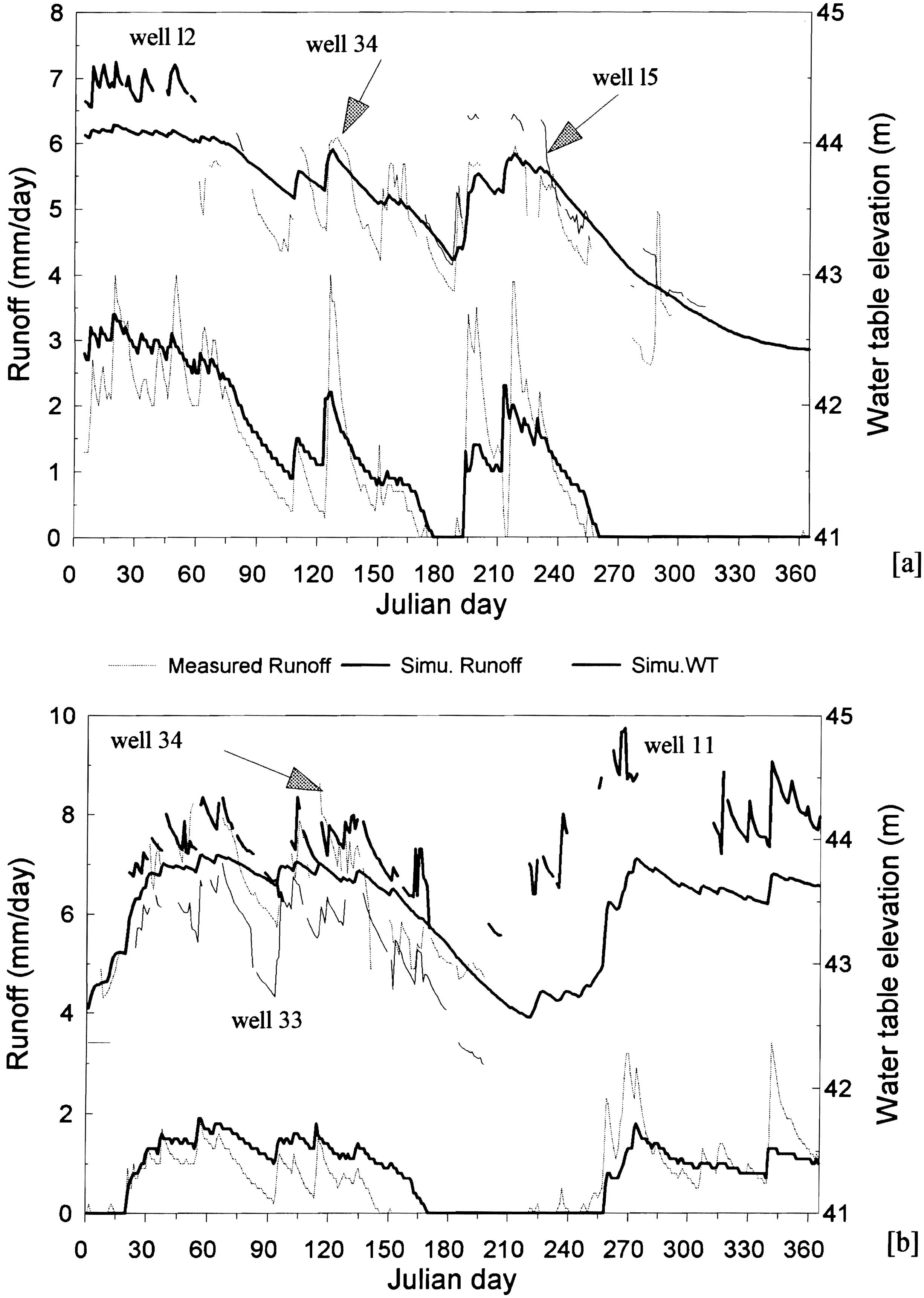

Fig. 7. FLATWOODS model calibration with measured runoff and groundwater table data in 1978 (a) and 1979 (b) from the Bradford Forest control watershed.

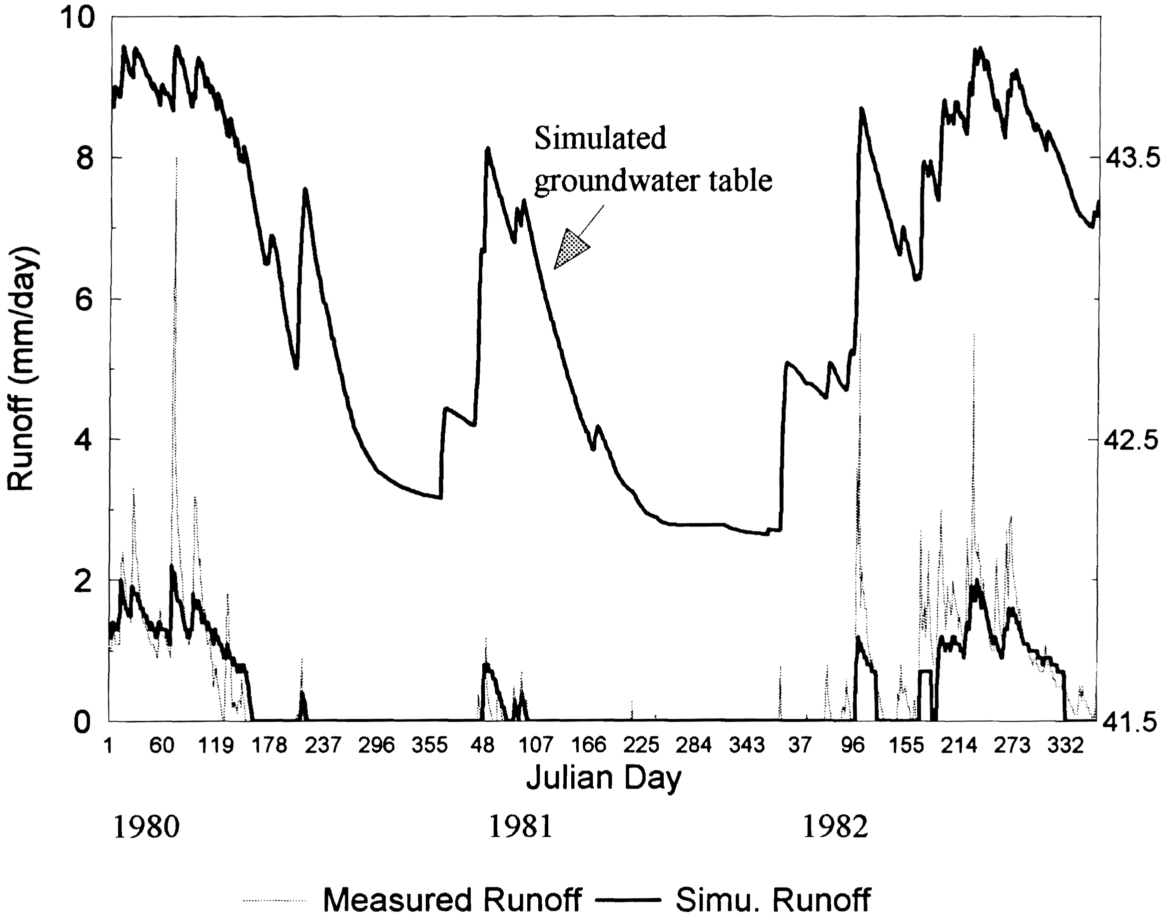

Fig. 8. FLATWOODS model calibration with measured runoff from the Bradford Forest control watershed during 1980-1982.

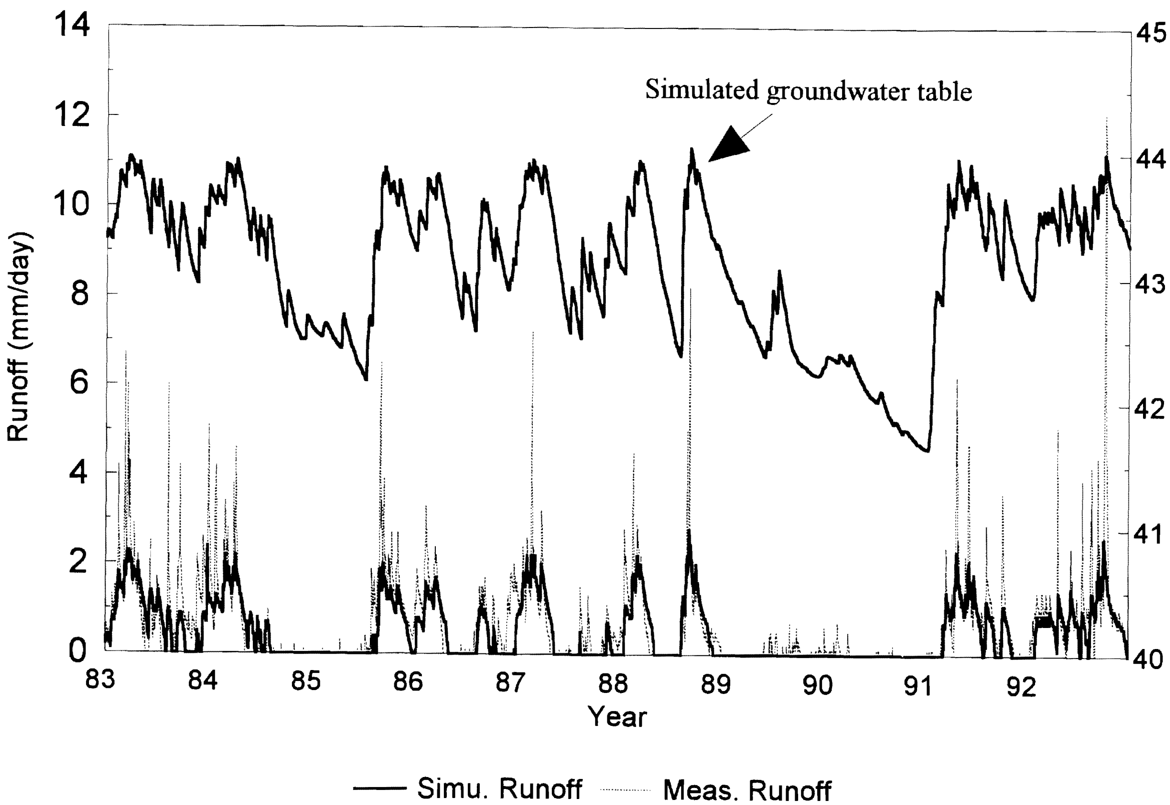

Fig. 9. FLATWOODS model verification with measured runoff from 1983 to 1992 from the Bradford Forest control watershed.

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The Effect of Composted Municipal Waste as a Soil Amendment on the Growth of Young Citrus Trees and *Phytophthora nicotianae*

T. L. Widmer*, J. H. Graham, and D. J. Mitchell

ABSTRACT

Phytophthora nicotianae **attacks citrus fibrous roots, causing decay and reduction of tree growth. One-year-old Orlando tangelo trees on Cleopatra mandarin rootstock were planted in a newly established grove at Lake Alfred, FL, which had received broadcast composted municipal waste (CMW) 3 mo. before planting. Trees were planted by either amending with additional CMW incorporated into the backfill or with no amendment. Half of the trees in each nonamended and CMW-amended treatment were inoculated with *P. nicotianae*. Stem diameters of CMW-amended trees were 17% greater than for nonamended trees after 2.75 yr. At times, soil populations of *P. nicotianae* were significantly higher in the CMW-amended treatment than in nonamended soil. Root density was not significantly affected by CMW treatment, but was reduced by *P. nicotianae*. There was a significant interaction between CMW and *P. nicotianae* with respect to tree growth, due to the apparent increase in *P. nicotianae* activity in the presence of CMW. After 2 yr, fruit yield from compost-amended trees was significantly higher than yield from nonamended trees.**

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INTRODUCTION

Citrus is one of the most economically important crops in Florida, with revenues exceeding one billion dollars each yr. Most of the 273 000 ha of citrus in Florida are planted on sandy soils low in organic matter and native fertility. These soils have a low cation exchange capacity and retain only small amounts of applied plant nutrients against the leaching action of rainfall and irrigation (Tucker et al., 1995).

Phytophthora nicotianae Breda de Haan causes a rot of fibrous citrus roots. Phytophthora root rot is a common problem in citrus nurseries (Zitko et al., 1987). In 1993, more than 90% of the nurseries surveyed in Florida were infested with *P. nicotianae* (Fisher, 1993). Commonly used rootstocks, such as sour orange (*Citrus aurantium* L.), Carrizo citrange (*C. sinensis* (L.) Osbeck × *Poncirus trifoliata* (L.) Raf.), and Swingle citrumelo (*C. paradisi* Macf. × *P. trifoliata*), range from susceptible to tolerant to Phytophthora root rot (Graham, 1990). However, because of citrus blight, virus diseases and other pest problems, use of tolerant rootstocks may not always be feasible (Graham, 1995). In infested nurseries, even tolerant rootstocks suffer serious root rot damage when over-watered (Zitko et al., 1987). In Florida, *P. nicotianae* is present in most citrus groves and can reduce fibrous root health and yield (Timmer et al., 1989). Applications of metalaxyl and fosetyl-Al fungicides have proved effective for control of fibrous root rot problems in mature citrus groves (Timmer et al., 1989). However, fungicide applications are not recommended if populations of *P. nicotianae* are less than 10-15 propagules cm^{-3} of soil. Also, *P. nicotianae* isolates that are resistant to metalaxyl from infested nurseries have been found in some citrus groves (Fisher, 1993).

These problems, along with increasing concern over use of chemicals applied to the soil that may reach ground water, have increased interest in alternative methods for management of Phytophthora root rot of citrus. Composted organic materials, such as bark, when added as a soil amendment, have been shown to suppress soilborne diseases caused by *Rhizoctonia solani*, *Pythium ultimum*, and *Fusarium oxysporum* f.sp. *conglutinans* (Lyda, 1982, Nelson and Hoitink, 1982, Trillas-Gay et al., 1986). Preliminary results (T. L. Widmer, 1995, unpublished) showed that composts from municipal solid waste sources were suppressive to Phytophthora root rot of citrus seedlings under greenhouse conditions. This study examines the effect of composted municipal waste (CMW) as a soil amendment on growth of newly planted Orlando tangelo trees and on activity of *P. nicotianae* on fibrous roots of the susceptible Cleopatra mandarin rootstock under field conditions.

MATERIALS AND METHODS

Study Site

A field experiment was conducted on Candler fine sand (Typic Quartzipsamments) at the Univ. of Florida/IFAS, Citrus Res. and Educ. Center in Lake Alfred, FL. The field site was fallow for 2 yr before the experiment, so it was assumed that endemic populations of *P. nicotianae* were very low if not absent. Approximately 3 mo. before planting, a CMW from Reuter Recycling (Pembroke Pines, FL) was broadcast onto the field plot at a rate of 100 Mg ha^{-1}. The compost was incorporated into the soil by disking to a depth of 15 to 30 cm.

Inoculum Preparation and Plant Infestation

A strain of *P. nicotianae* isolated from citrus roots (R-1) was used as the inoculum source. Chlamydospores were prepared by the method of Mitchell and Kannwischer-Mitchell (1992). Sterilized Candler fine sand (≈5% w/w moisture) was infested with the chlamydospores to a level of 70 chlamydospores cm^{-3} of soil.

One-year-old Orlando tangelo trees (*Citrus reticulata* Blanco × *C. paradisi*) on Cleopatra mandarin rootstock (*C. reticulata*) were acquired from a commercial nursery, grown in Metro-Mix 500 (The Scotts Co., Marysville, OH), and fertilized with slow-release 17-7-10 (N-P_2O_5-K_2O) Osmocote fertilizer and Micromax micronutrients (The Scotts Co., Marysville, OH) in 1000-cm^3 citripots. One month before planting, the trees were inoculated with chlamydospores of *P. nicotianae* by applying a 0.5-cm layer of infested soil on top of the potting medium in each container to be inoculated (≈3000 chlamydospores pot^{-1}). The drainage holes of the citripot were taped shut. The plants were flooded for 7 d, above the level of the medium in the pot, to promote zoospore release and infection by *P. nicotianae*. Inoculated trees were assayed for pathogen population and moved to a screenhouse one wk before planting, to allow adaptation to field conditions.

Preparation of Field Plot

The experiment was a split-plot design with eight blocks of eight trees. Additional CMW, the main factor, was incorporated into the backfill, at a level of ≈20% of the total volume, in four randomized blocks. Within each block, trees were alternated between those noninfested and infested with *P. nicotianae* as the subfactor. A plastic mesh with 1-mm-square holes was placed around the roots of each tree to delineate the zone where new roots emerged from the root ball. The trees were planted in the center of the holes, which were then backfilled and watered well to pack soil around the roots and eliminate air pockets. The trees were fertilized under procedures recommended by IFAS for a newly-established grove in central Florida (Tucker et al., 1995).

Two yr after planting, a layer of the CMW was applied to the compost-amended plots as a top dressing 5-cm thick, at an application-area rate of 140 Mg ha^{-1}, extending just beyond the drip line.

Tree Growth and Sample Analysis

Soil samples were initially taken in December 1992 (3 mo after planting), and then in the spring and fall of each subsequent yr with either a 100-cm^3 (2.5-cm diameter) or 980-cm^3 (7.5-cm diameter) volume auger. Soil was collected from under the canopy, approximately halfway between the trunk and drip line. Citrus roots were sieved from the soil with a 2-mm-mesh screen and weighed. Population densities of *P. nicotianae* were estimated by the modified procedure of Timmer et al.

(1988). The sieved soil was placed in Styrofoam cups with drainage holes and watered to field capacity. After 3 d, 10 g of soil were mixed with 40 mL of 0.25% water agar. One mL of the soil solution was plated on a Phytophthora-selective medium (Mitchell and Kannwischer-Mitchell, 1992).

The soil was analyzed 4 mo after planting for its C:N ratio by the Soil Testing Laboratory at the Univ. of Florida (Gainesville) using the Walkley-Black procedure (Allison, 1965) for determination of organic C and a total Kjeldahl procedure (Bremner, 1965) for determination of N.

In the fall of the second yr, spring flush leaf samples were collected from each tree (four samples tree^{-1}). The leaves were composited from four trees of treatments in each block and dried at 65°C. The dried leaves were ground into a fine powder using a Cyclotec 1093 Sample Mill (Tecator, Inc., Herndon, VA). A Buchi 322 distillation unit (Buchi Laboratories, Switzerland) with a Brinkman automatic titration unit (Brinkman Instruments, Switzerland) was used for N analysis according to the procedures set by the manufacturer. Tissue phosphorus (P) was determined by ICP-AES (Plasma 40, Perkin-Elmer Corp., Norwalk, CT) after the samples were ashed.

The effect of the treatments on tree growth was evaluated by measuring the stem diameter of the tree in the spring and fall of each year, 28 cm above the soil line. Fruit was harvested in the second yr after planting, and the weight of fruit tree^{-1} was measured.

Data for each evaluation were analyzed for variance, and significance of treatment differences determined using repeated measures analysis, least significant differences (LSD) or paired t-tests, with SAS statistical software (SAS Institute, Carey, NC).

RESULTS AND DISCUSSION

Populations of *P. nicotianae* were detected in the roots of some trees not inoculated at the beginning of the study. Either the trees were infected in the nursery before the experiment, or there was residual inoculum in the field before planting. Although this meant that the treatments did not have the same number of replications, pertinent statistical analysis was performed.

Reuter CMW, amended to soil at 20% v/v, has been shown to suppress root rot in greenhouse bioassays with 5-wk-old seedlings (T. L. Widmer, unpublished, 1995). However, one obstacle to the use of composts and other biocontrol agents for disease suppression is the inability to demonstrate effectiveness in the field. During this study, the CMW did not appear to have a significant suppressive effect on the pathogen. In fact, populations of *P. nicotianae* were consistently higher in the compost-amended plots than in the nonamended plots at each of the times sampled (Fig. 1).

Although CMW increased pathogen activity, it also significantly increased growth of the trees (Fig. 2). Over a 2.75 yr period after planting, compost significantly increased stem diameters for both the infected and non-infected trees compared to the nonamended trees. Overall, CMW increased stem diameter 17% over values for nonamended trees. There was a significant interaction between the presence of CMW and *P. nicotianae*, in that the increase in stem diameter for CMW-amended plots was smaller in the presence of the pathogen than for the nonamended plots. Indeed, *P. nicotianae* alone did not have a significant impact on tree growth rate in the absence of CMW. This is consistent with the increase in *P. nicotianae* due to CMW.

Since the increase in tree growth did not appear to be related to pathogen control, other explanations, such as a nutritional advantage of CMW to the tree, were considered. Nitrogen is the most important nutrient for optimal growth and yield of citrus (Tucker et al., 1995), but leaf analysis did not show a significant increase in leaf N concentration for compost-amended trees. Nitrogen concentration was 2.2% for both the compost-amended and nonamended trees, slightly below the optimum range of 2.5-2.7% (Koo, 1984). Leaves did not show visible N deficiency symptoms, however. Both CMW and nonamended treatments had sufficient concentrations

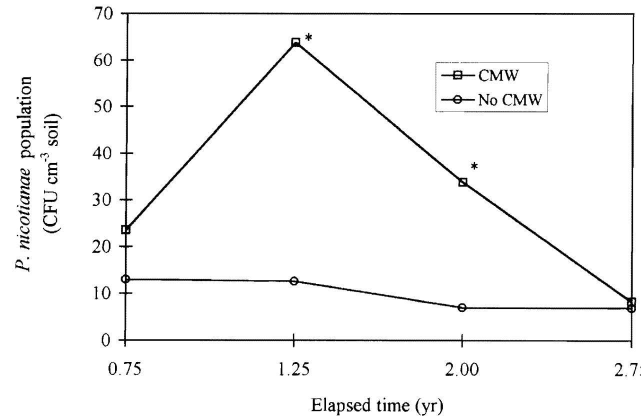

Fig. 1. The effect of composted municipal solid waste (CMW) on the recovery of soil populations of *Phytophthora nicotianae* from the rhizosphere of Orlando tangelo trees on Cleopatra mandarin rootstock. Points followed by an * indicate significant differences (P = 0.05) at the specified time period using a paired t-test.

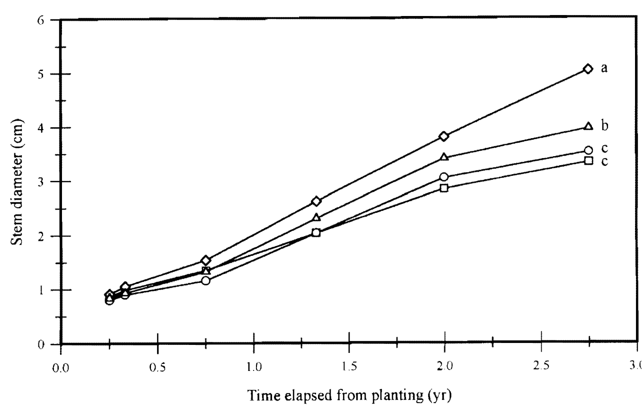

Fig. 2. The effect of composted municipal solid waste (CMW) and infection by *Phytophthora nicotianae* on the growth of young Orlando tangelo trees on Cleopatra mandarin rootstock. No CMW, not infected (□); No CMW, infected (○); CMW, not infected (◇); and CMW, infected (△). Curves followed by similar letters are not significantly different (P = 0.05) using the GLM procedure for repeated measures analysis of variance.

of P, at 0.17%. Carbon:nitrogen ratios of 16.1 and 15.5 for compost-amended plots and nonamended plots, respectively, were not significantly different.

Another explanation for the increase in tree growth may be that the physical properties of the soil were altered by the addition of compost. Organic matter has a fundamental effect on the water-holding capacity and cation exchange and buffering properties of citrus soils (Webb et al., 1988; Obreza, 1995). Humates that comprise a large portion of organic matter in the soil have a large exchange capacity and greatly affect the availability of nutrients to plant roots (Schnitzer and Poapst, 1967). Humates added to a soil increased the stem cross-section area of young citrus trees (Webb et al., 1988). Young citrus trees suboptimally irrigated did not grow to the same size as those optimally supplied with water (Goell et al., 1981). Compost has been shown to increase water retention and infiltration into the soil (Diener et al., 1993) and, therefore, should make water more available to the plant (Lyda, 1982; Obreza, 1995). Compost can also improve water drainage (Lutz et al., 1986).

Compost did not significantly affect root density, except at 2 yr after planting (Table 1). In a study done on beans, humate increased root initiation (Schnitzer and Poapst, 1967). If humate affects citrus root formation, sampling was not sensitive enough to measure the responses. Major roots of small trees are often unevenly distributed and fibrous roots may occur in patches (Castle, 1987). Most of the trees were sampled with only one core of soil tree^{-1} to avoid damage to the root system. Perhaps multiple, smaller core samples would be required to estimate root density more accurately. Root density was significantly reduced on trees with *P. nicotianae* during the early part of the experiment (Table 1), and was consistently lower throughout the study. This is consistent with other studies that have shown that *P. nicotianae* reduces fibrous root density for mature trees (Sandler et al., 1989).

The CMW had a positive effect on the yield and average fruit weight 2 yr after planting, whereas the effect of *P. nicotianae* was not significant ($P = 0.05$). There was also no significant interaction between the CMW treatment and the presence of *P. nicotianae* on either the number of fruits tree^{-1} or average fruit weight (Table 2). Fruit yield is highly variable, because young trees do not consistently bear fruit until after they are 5 yr old (Jackson, 1991). Although N is the key fertilizer element affecting early yield response (Tucker et al., 1995), available N nutrition does not appear to be increased by treatments with the source of CMW we used (Eichelberger, 1994).

Improved water holding capacity due to the compost may be the most significant factor affecting the yield increase and perhaps also responsible for the increase in pathogen activity. *Phytophthora* spp. proliferate under warm, moist conditions (Weste, 1983). The CMW, by increasing water retention, may be conducive to an increase in production of sporangia and, therefore, the release of numerous motile zoospores.

Table 1. Effect of composted municipal solid waste (CMW) and infection by *Phytophthora nicotianae* on root mass density of Orlando tangelo trees on Cleopatra mandarin rootstock, 0.75 to 2.75 yr after planting in the field.

Treatment	Fresh root weight (mg cm^{-3} soil)			
	0.75 yr	1.25 yr	2.00 yr	2.75 yr
CMW (-)	2.96 a	8.82 a	5.67 b	4.08 a
CMW (+)	2.51 a	9.21 a	9.76 a	3.96 a
P. nicotianae (-)	3.60 a	11.08 a	8.75 a	4.57 a
P. nicotianae (+)	2.42 b	8.27 b	7.34 a	3.82 a

Means for CMW or *P. nicotianae* treatments followed by the same letter are not significantly different ($P = 0.05$) according to a paired t-test.

Table 2. Effect of composted municipal solid waste (CMW) and infection by *Phytophthora nicotianae* on the number of fruit per tree and the average weight of individual fruit 2 yr after planting in the field.

Treatment				
CMW	*P. nicotianae*	N	fruit tree^{-1}	fruit weight (g)
-	-	12	2.5 b	92 b
-	+	20	4.7 ab	135 ab
+	-	5	5.6 ab	221 a
+	+	27	9.9 a	173 a

Means followed by the same letter are not significantly different ($P = 0.05$) according to LSD analysis.

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A Potential Evapotranspiration Prediction Submodel For Multi-dimensional Water Flow in Soils

Ali Fares* and R. S. Mansell

ABSTRACT

Net radiation and potential evapotranspiration are required input parameters for most crop growth models and multi-dimensional water flow and solute transport models. Field estimation of these parameters is a lengthy and costly process. An analytical evapotranspiration submodel (ETM) was developed as a simple means to predict daily extraterrestrial radiation, clear sky solar radiation, net radiation, pan evaporation and potential evapotranspiration from a minimal set of weather data: minimum and maximum daily temperatures, latitude and altitude of the location, ratio of actual to maximum possible sunshine hours, day of the year, and reflectivity of the surface. Such weather data sets are readily available for most locations and do not require intensive data collection. Simulations using the ETM model compared favorably to published measured data for these variables. ETM is a compact analytical model that offers rapid long-term estimates of weather data. It can easily serve as a submodel of multi-dimensional models for water flow and solute transport in soils.

Crop growth models and multi-dimensional water flow and solute transport models can be used to optimize existing crop management practices and/or to evaluate possible alternative practices in order both to increase crop production and minimize groundwater and surface water degradation. These models require various combinations of daily or hourly solar radiation (R_s), pan evaporation (PE), and potential evapotranspiration (ET_o) data. Field measurement of these parameters is usually limited to research contexts, when small areas are subject to intensive study. Collection of such data for long periods of time, and for different locations and environments, can be prohibitive due to excessive costs and labor demands. Reliable mathematical submodels can serve as realistic substitutes when estimating these parameters.

So-called "weather generators" (Keller, 1987) can be used to estimate R_s and ET_o using available meteorological data as inputs. These generators may provide reasonable data sets for exploring possible modeling scenarios (Hook and McClendon, 1992). The Penman equation (1948) is generally accepted as the most suitable method for estimating ET from uniform canopies (Dolman, 1988). Using a more stringent analysis, Shuttleworth (1976) developed a multi-layer model to determine ET in forests. However, the theoretical advantages of the Shuttleworth model are more than offset by the practical difficulties of developing sufficiently accurate estimates of leaf resistance for all levels of the tree canopy (Stewart, 1984).

Thus, in practice, the simpler Penman equation and its derivatives, such as the Priestley-Taylor (1972) approach, are advantageous. The Priestley-Taylor equation is a simplified form of the Penman equation most reliable in humid climates, where the aerodynamic component has been deleted and the energy term multiplied by a constant α (Jensen et al., 1989):

$$\Phi = \alpha\frac{\Delta}{\Delta + \gamma}(R_n - G) \quad (1)$$

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where $\Phi = \lambda[ET]$ is vapor flux density (MJ m^{-2} t^{-1}), λ is latent heat of vaporization (J kg^{-1}), R_n is net radiation flux (MJ m^{-2} t^{-1}), G is soil heat flux (MJ m^{-2} t^{-1}), γ is a psychometric constant (0.067 kPa°C^{-1}), and Δ is the slope of the saturated vapor pressure curve for air (kPa°C^{-1}). Evaporation in mm t^{-1} is calculated by dividing λET by the latent heat of vaporization (M), which has units of MJ kg^{-1}. Alpha (α), an empirical parameter, depends upon the nature of the surface, the air temperature and time of day (Viswanadham et al., 1991). Barton (1979) suggested that α has a value close to unity for forest environments; however, Viswanadham et al. (1991) determined mean values for α of 1.16 (± 0.56) and 1.03 (± 0.13). Priestley and Taylor (1972) obtained a mean α value of 1.26 for an extensive wet surface in the absence of advection. Jury and Tanner (1975) showed that α increases with heat advection from surrounding areas, and suggested a procedure for adapting the Priestley-Taylor equation to such conditions.

Objectives for our work were to: a) use published equations and minimum weather data sets to estimate input parameters to the Priestley-Taylor equation; and b) use previously calculated parameters for the Priestley-Taylor equation to estimate SR, PE and PET. Published daily minimum and maximum air temperature data are generally available for most areas of the U.S. or can be easily obtained from appropriate weather records.

MODEL DEVELOPMENT

A new analytical model ETM (A Potential **E**vapo-**T**ranspiration Prediction **M**odel) is introduced here for

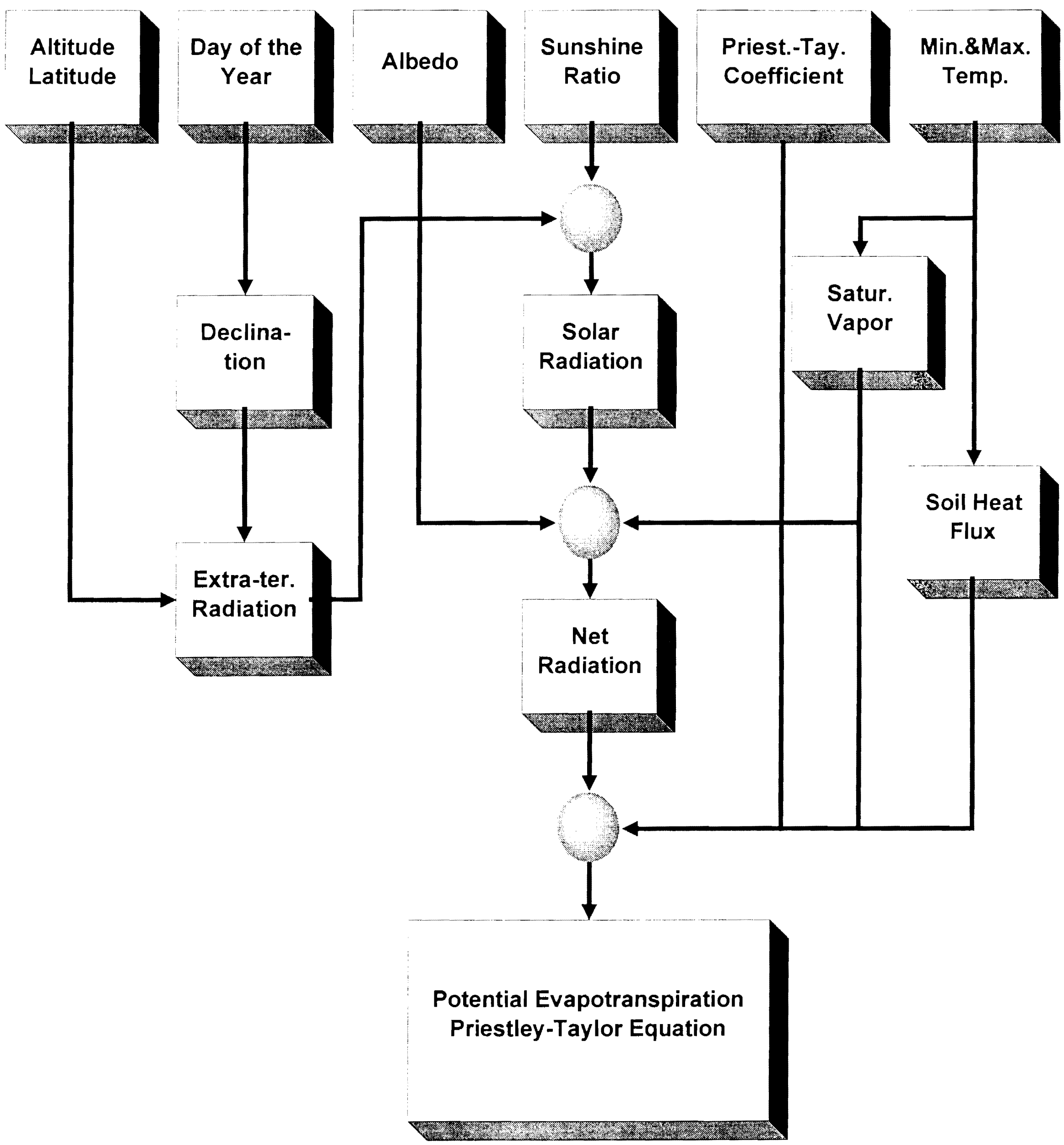

Fig. 1. Flow chart of the ETM model.

describing pan evapotranspiration in soil-water systems. The model is based on the Priestley-Taylor equation, with daily air minimum and maximum temperatures being used as the main variable input parameters for a given location.

During the first step of our procedure (Fig. 1), the following input parameters are calculated or input: the saturated air vapor pressure; the heat flux and net radiation based on day of the year, altitude and latitude of the location; albedo of the surface; and minimum and maximum daily temperatures. These variables then are used as input parameters to the Priestley-Taylor equation to determine either the PET or the PE, depending upon the value of the albedo. The major steps of our procedure are as follows:

Estimation of Input Parameters for the ETM Model

Calculation of the daily total net radiation (R_n) at the surface of the earth

Daily total values of R_n (MJ m^{-2} d^{-1}) can be determined using several procedures found in the literature. Net radiation, if not measured in the field, can be estimated from daily total incoming solar radiation, R_s (MJ m^{-2} d^{-1}), and outgoing thermal or long-wave radiation. The daily net radiation calculation requires estimation of total incoming solar radiation (R_s), clear sky short wave radiation (R_{so}) and saturation vapor pressure at the dewpoint temperature (minimum temperature is used as the dewpoint temperature). The following relationship was proposed by Penman (1948) and modified by Wright (1982) to estimate net radiation:

$$R_n = (1-\beta)R_s - \sigma\frac{T^4_{maxk} + T^4_{mink}}{2}(a_1 - 0.139\sqrt{e_d})\left(a\frac{R_s}{R_{so}} + b\right) \quad (2)$$

where β is albedo or reflectivity of the surface, σ is the Stephan-Boltzman constant (4.903 × 10^{-9} MJ m^{-2} d^{-1} K^{-1}), T_{maxk} is maximum daily air temperature (°K), T_{mink} is minimum daily air temperature (°K), e_d is saturation vapor pressure at the dewpoint temperature (kPa), R_{so} is clear-sky short wave radiation (R_s with no clouds; MJ m^{-2} d^{-1}), and a_1, a, b are empirical coefficients. Accepted values for β are: 0.05 for water surfaces, a range of 0.15 to 0.60 for bare soil surfaces, 0.25 for most agricultural crops, and ≈ 0.10 for forests. Wright (1982) estimated the a_1 empirical coefficient using:

$$a_1 = 0.26 + 0.1e^{-[0.0154(J-180)]^2} \quad (3)$$

where J is day of the year (1 to 365). For $R_s/R_{so} > 0.7$ (few clouds), a = 1.126 and b = -0.07; for $R_s/R_{so} < 0.7$ (cloudy), a = 1.017 and b = -0.06. The value of a_1 predicted by equation (3) was limited to ≤ 4 during late fall and winter months. Clear-sky short wave radiation, R_{so}, was estimated by Jensen et al. (1989) as:

$$R_{so} = 0.75R_A \quad (4)$$

where R_A is extraterrestrial radiation in MJ m^{-2} d^{-1}.

Solar radiation R_s can be measured directly with reliable instruments ranging in complexity from a spring-wound chart and bimetallic sensors to thermopile sensors or silicon cells used in connection with electronic integrators and microprocessor-controlled recorders. However, estimates of daily solar radiation also can be made using extraterrestrial radiation, R_A. Doorenbos and Pruitt (1977) recommended using a generalized form of the Penman equation to estimate R_s:

$$R_s = \left(0.25 + 0.5\frac{n}{N}\right)R_A \quad (5)$$

where R_A is the extraterrestrial solar radiation, n is the number of actual bright sunshine hours, and N is the maximum possible sunshine hours for that determinant location on that date.

Values of R_A for various months of the year and latitudes are given in Doorenbos and Pruitt (1977). Monthly and daily values of R_A can also be calculated using the following set of equations developed by Duffied and Beckman (1980):

$$R_A = 37.58 \cdot d_r[\omega_s \cdot Sin(\xi) \cdot Sin(\delta) + Cos(\xi) \cdot Cos(\delta) \cdot Sin(\omega_s)] \quad (6)$$

where R_A is in MJ m^{-2}d^{-1} and ξ is latitude of the location in radians (-S,+N). The declination, δ, in radians can be estimated as:

$$\delta = 0.4093Sin\left(2\Pi\frac{(284+J)}{365}\right) \quad (7)$$

where J is day of the year. The term d_r in equation 6 is relative distance of the earth from the sun, where:

$$d_r = 1 + 0.033Cos\left(\frac{2\Pi J}{365}\right) \quad (8)$$

The sunset hour angle, ω_s, in radians can be calculated as:

$$\omega_s = ArcCos[-Tan(\xi)Tan(\delta)] \quad (9)$$

Daily soil heat flux (G)

The average daily soil heat flux was approximated by Wright and Jensen (1972) as:

$$G = (T_a - T_p)C_s \quad (10)$$

where T_a is average daily air temperature (°C) at the z height and T_p is the average daily air temperature (°C) at that height for the previous 3 days. Parameter C_s is the general heat conductance for the soil surface, equal to about 0.38 MJ m^{-2}d^{-1}(°C^{-1}) for a silt loam soil (Allen et al. 1989).

Saturation vapor pressure (e_d)

Saturation vapor pressure (e_d) in kPa at temperature T (°C) was calculated using the method of Tetens (1930):

$$e_d = \exp\left(\frac{16.78T + 117}{T + 237.3}\right) \quad (11)$$

Slope of the saturated vapor pressure function (Δ)

Slope of the saturated vapor function was calculated by taking the derivative of the saturated vapor pressure equation with respect to T:

$$\Delta = \frac{4098 e_d}{(T + 237.3)^2} \quad (12)$$

Psychometric constant (γ)

The psychometric constant, γ (kPa°C^{-1}), was calculated as follows:

$$\gamma = \frac{c_p P}{\lambda \varepsilon} \quad (13)$$

where c_p is the specific heat of moist air at constant pressure (1.01 × 10^{-3} MJ kg^{-1} C^{-1}), P is atmospheric pressure (kPa), ε is the molecular-weight ratio of air to water (0.622), and λ is the latent heat of vaporization (MJ kg^{-1}).

Latent heat of vaporization (λ)

Latent heat of vaporization was calculated according to Harrison (1963) as:

$$\lambda = 2.5 - (2.361 \times 10^{-3}) T_a \quad (14)$$

where T_a is air temperature (°C). Based on virtual temperature (T'_v) and the ideal gas law, atmospheric density (ρ) was calculated by Allen et al. (1989) as:

$$T'_v = \frac{T_a}{1 - 0.378\frac{e_d}{P}} \qquad \rho = \frac{1000P}{T'_v R} \quad (15)$$

where T'_v and T_a have units of °K, ρ has units of kg m^{-3}, and R is the specific gas constant for dry air (286.9 J kg^{-1} °K^{-1}). Virtual temperature represents the temperature of a dry air parcel with heat content equivalent to that of a similar moist parcel.

The ideal gas law was used by Allen et al. (1989) to estimate mean atmospheric pressure at a given altitude by assuming a constant temperature lapse rate; thus, the resulting equation for P as developed by Burman et al. (1987) is:

$$YP = P_o\left(\frac{T_o - Y(z - z_o)}{T_o}\right)^{\left(\frac{g}{\Omega R}\right)} \quad (16)$$

where P_o and T_o are known atmospheric pressure (kPa) and absolute temperature (°K) at elevation z_o (m), respectively, and P is the desired pressure estimate at elevation (altitude) z. Parameter Ω is the assumed constant adiabatic lapse rate. Allen et al. (1989) suggested a Y value of 0.0065 K m^{-1} for saturated air and of ≈ 0.01 K m^{-1} for dry air. Gravitational acceleration (g) equals 9.8 m s^{-2}. Reference values for P_o, T_o, and z_o were set equal to those for the standard atmosphere at sea level, which are 101.3 kPa, 288 °K, and 0 m, respectively (List, 1984).

Integration of Input Parameters Into the Priestley-Taylor Equation

The Priestley-Taylor equation (1) has six input parameters: the Priestley-Taylor coefficient (α), slope of the saturation vapor pressure curve for water (Δ), net radiation (R_n), soil heat flux (G), psychrometric constant (γ), and latent heat of vaporization (λ). Figure 1 shows schematically how these input parameters are related via equation 1.

MODEL VALIDATION

Validation of the Net Radiation Component

Each of the submodel components was validated using experimental data from the literature. The term Δ/(Δ+γ) of the Priestley-Taylor equation was calculated for different elevations and temperatures and compared with values reported by Jensen et al. (1989). ETM values were lower than those of Jensen et al. (1989) by 0.01% to 0.52% (Table 1). Such small differences suggest that the ETM submodel provided a good estimate of this term for a wide range of altitudes and latitudes in the northern hemisphere.

Daily extra-terrestrial solar radiation calculated by ETM agreed well with values estimated by Gates (1962) for a location of similar latitude to Gainesville, FL (Fig. 2A). According to equation (5), daily solar radiation was determined using the predicted extra-terrestrial solar radiation as calculated in the previous step. Clear-sky solar radiation determined for 30° latitude also compared well to data published by Budyko (1963) (Fig. 2B). Daily net radiation can be calculated using equation (2), feeding into it values for estimated clear sky-solar radiation, minimum and maximum daily temperatures, and albedo (reflectivity of the surface).

Prediction of Pan Evaporation

Daily minimum and maximum temperature data for Gainesville, FL (latitude = 29.4° N, altitude = 54 m above mean sea level, and longitude = 82.16° W) have been recorded for the past 91 years (1903 - 1994). A daily mean and a standard deviation were calculated for minimum and maximum temperatures, and for pan evaporation (PE), using this data set. The minimum and maximum temperature data then were used in turn to define "cold", "mean", and "hot" years (Fig. 3) as follows:

$$\begin{aligned} &HotYear T^{hot}_{min} = T^{mean}_{min} + 1.96 \times SD ; T^{hot}_{max} = T^{mean}_{max} + 1.96 \times SD \\ &MeanTempYear T^{mean}_{min} = T^{mean}_{min} ; T^{mean}_{max} = T^{mean}_{max} \\ &ColdYear T^{cold}_{min} = T^{mean}_{min} - 1.96 \times SD ; T^{cold}_{max} = T^{mean}_{max} - 1.96 \times SD \end{aligned} \quad (17)$$

Temperature data for these three representative types of years were used to calculate the corresponding PE values, and a range of values of α for the Priestley-Taylor equation were used with the "cold", "mean", and "hot" year temperature data to simulate three levels of PE for Gainesville, FL. Estimated data from the **ETM** model were compared to experimental PE measured daily over the last ten years (1984-1994). A daily measured mean PE and a standard deviation were calculated using these field

Table 1. Simulated and calculated variation of Δ (Δ + γ) with elevation and temperature.

	A. Values Calculated by Jensen et al. (1989)							B. Values Estimated by the ETM Model						
Elev.(m)	0	500	1000	1500	2000	2500	3000	0	500	1000	1500	2000	2500	3000
°C														
0	0.403	0.417	0.432	0.446	0.462	0.477	0.493	0.403	0.418	0.433	0.449	0.465	0.482	0.499
5	0.479	0.494	0.509	0.524	0.539	0.554	0.570	0.479	0.495	0.511	0.527	0.543	0.559	0.576
10	0.553	0.567	0.582	0.597	0.611	0.626	0.640	0.553	0.568	0.584	0.599	0.615	0.630	0.646
15	0.621	0.635	0.649	0.663	0.676	0.690	0.703	0.621	0.636	0.651	0.665	0.680	0.694	0.708
20	0.683	0.696	0.708	0.720	0.733	0.745	0.756	0.683	0.696	0.710	0.723	0.736	0.748	0.761
25	0.736	0.748	0.759	0.770	0.780	0.791	0.801	0.736	0.748	0.760	0.772	0.783	0.794	0.805
30	0.782	0.792	0.802	0.811	0.820	0.829	0.838	0.782	0.792	0.803	0.813	0.822	0.832	0.841
35	0.820	0.829	0.837	0.845	0.853	0.860	0.868	0.820	0.829	0.838	0.846	0.854	0.862	0.870
40	0.852	0.859	0.866	0.873	0.879	0.886	0.892	0.852	0.859	0.866	0.873	0.880	0.887	0.893
45	0.877	0.884	0.890	0.895	0.901	0.906	0.912	0.877	0.884	0.890	0.896	0.901	0.906	0.912
50	0.899	0.904	0.909	0.914	0.918	0.923	0.927	0.898	0.904	0.909	0.914	0.918	0.923	0.927
SUM	100.0	100.0	100.0	100.0	100.0	100.0	100.0	99.99	99.93	99.82	99.72	99.65	99.58	99.48
(A - B)%								0.010	0.070	0.180	0.280	0.353	0.421	0.521

data. Using these two terms, three distinct PE levels were calculated (a high, a mean and a low level) as follows:

$$HighPE = PE_{avg} + SD$$
$$MeanPE = PE_{avg} \quad (18)$$
$$LowPE = PE_{avg} - SD$$

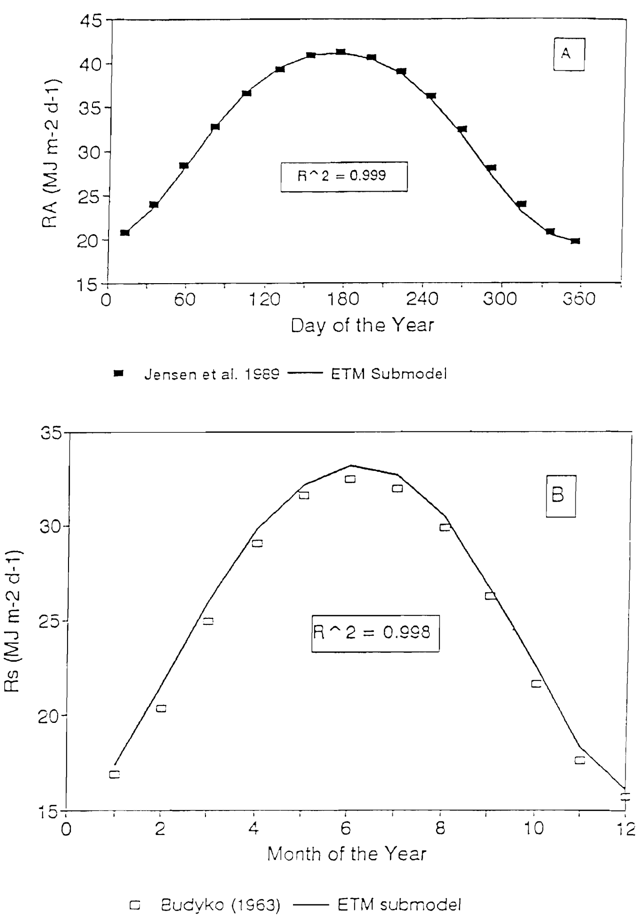

Fig. 2. Extraterrestrial radiation and cloudless solar radiation for a location at 30° latitude.

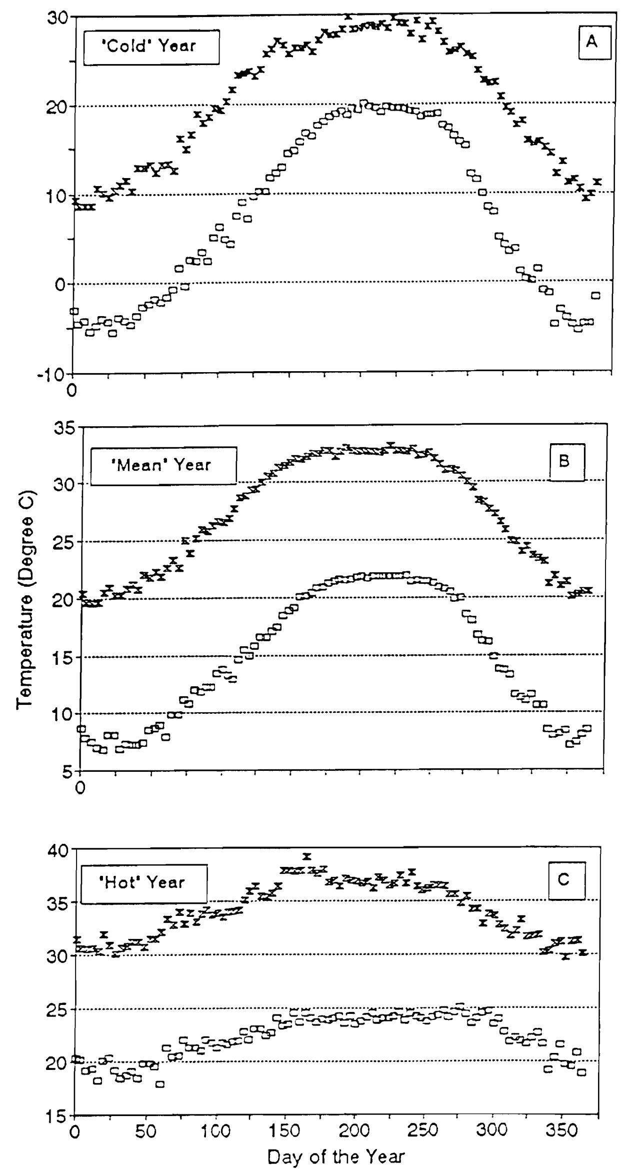

Fig. 3. Daily minimum and maximum temperature for "Hot", "Mean", and "Cold" years at Gainesville, FL.

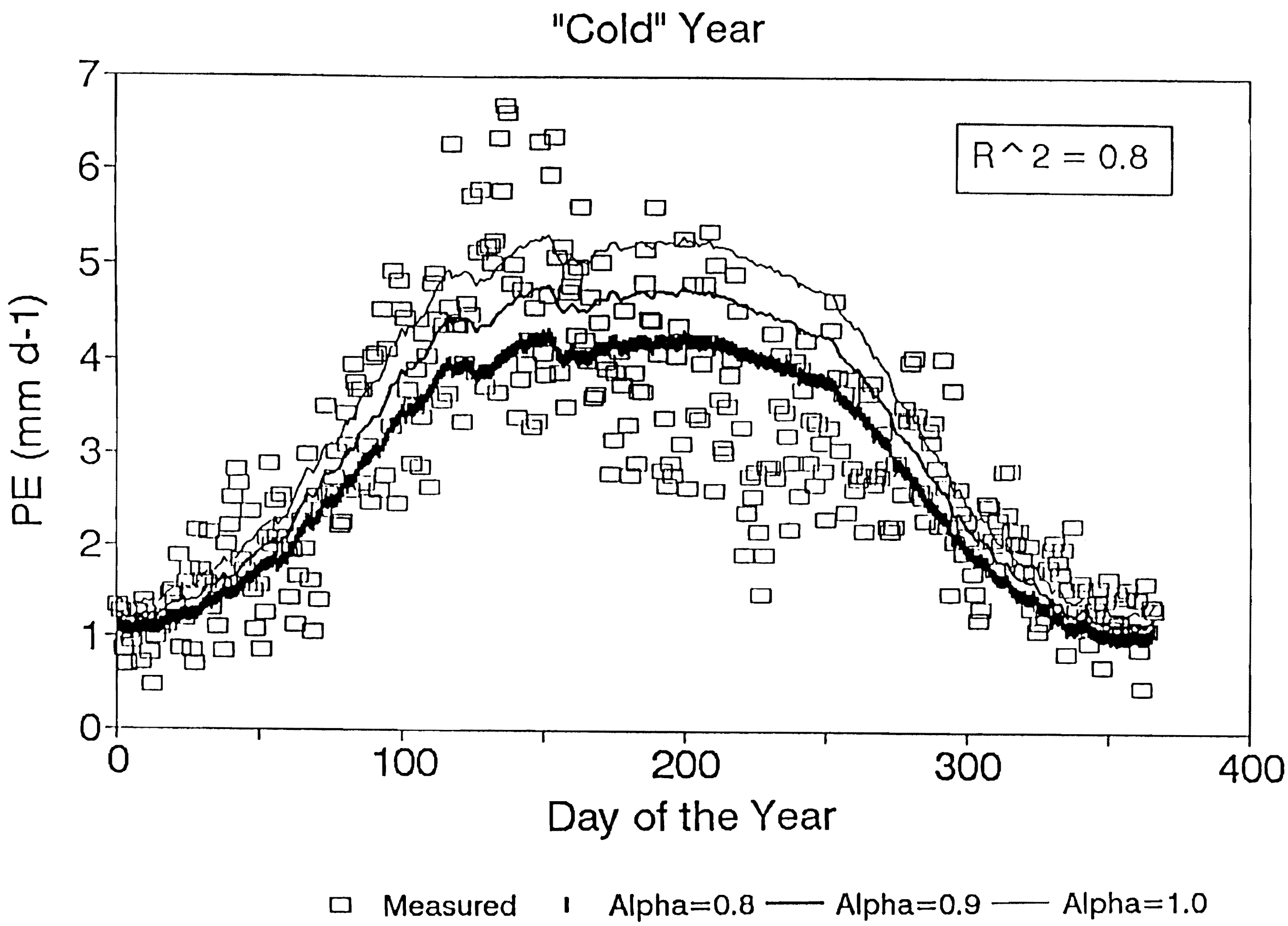

Fig. 4. Measured low PE level, and simulated PE, for a "cold" year at Gainesville, FL.

Minimum and maximum temperatures for the previously defined "cold", "mean" and "hot" years then were used to simulate PE. Simulated PE using the "cold" minimum and maximum temperatures were compared to the measured low PE. Similarly, simulated PE using the "mean" and "hot" minimum and maximum temperatures were compared to measured mean PE and low PE, respectively. Different values of the Priestley-Taylor coefficient, α, were used. Alpha values of 0.8, 0.9, and 1.0 were used with the "cold" year temperature data. In Fig. 4, simulated PE for the "cold" year and measured low PE are plotted. Measured PE is highly variable, which makes it difficult to determine which simulated PE function fit better. A linear regression analysis was conducted for both simulated data sets with respect to the measured PE data. The results produced an $R^2 = 0.8$ for both simulations, signaling a relatively good fit between simulated and experimental data sets given the variability inherent in the measured data. Figure 5 shows two simulated data sets of "hot" weather year potential evaporation data and associated levels of measured PE data. The simulated data using an alpha value of 1.0 and 0.9 track the measured PE data throughout the year better than the other two sets of simulated PE data. Simulated PE with an alpha value of 0.9 under-estimated the measured PE starting at day 125 until the end of the year. A regression analysis between each of the two simulated data sets and measured high PE resulted in an R^2 value of 0.84. These two simulated data sets provided a better description of the corresponding measured PE than those of the "mean" weather year (Fig. 6).

Prediction of Pan Evapotranspiration

Daily pan evapotranspiration

Figure 7 shows five-day averages of measured evapotranspiration for turfgrass (*Cynodon dactylon* L.) grown in lysimeters at Fort Lauderdale, FL during 1965 (Stewart and Mills, 1967), with the water table maintained 30 cm below the soil surface. The relatively high water table and good vegetative coverage of the soil surface fits the definition of "a well watered vegetative surface" (Penman, 1956). The ETM submodel has been used to simulate daily potential evapotranspiration using appropriate climatological data and an albedo value of 0.23, corresponding to a grass surface. Both measured ET and simulated PET followed bell-shaped curves. Even though substantial variability occurred in the measured ET data, the simulated PET curve tracked through the middle of the measured ET data, indicating good agreement between the measured ET and simulated PET.

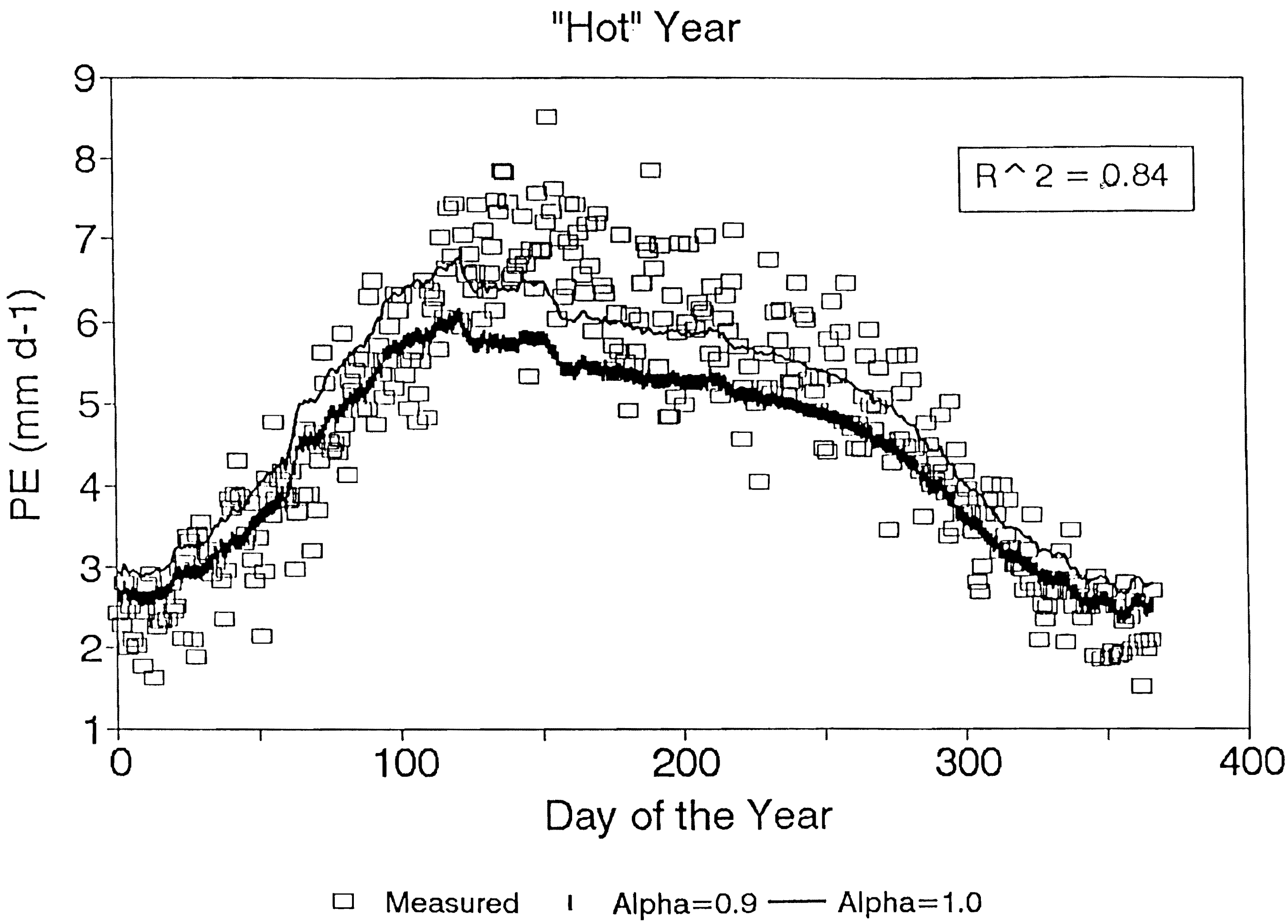

Fig. 5. Measured mean PE level, and simulated PE, for a "hot" year at Gainesville, FL.

Maximum rates of measured ET (5.0 mm day^{-1}) and simulated PET (4.75 mm day^{-1}) were registered during the months of April and May. Relatively lower ET and PET during the summer months was due in part to near-daily afternoon showers, usually heavy sky cloud coverage, and concomitant low afternoon vapor pressure deficits. Lowest measured ET and simulated PET values were found during the winter months of December and January.

Monthly potential evapotranspiration

Both total monthly measured ET (Stewart and Mills, 1967) and simulated PET using the ETM submodel for the previously mentioned turfgrass experiment at Fort Lauderdale are plotted in Fig. 8. A regression analysis between the measured and simulated data resulted in a regression coefficient, R^2, of 0.97. This high regression coefficient confirms the similarity between measured and simulated PET. However, simulated data were slightly higher than measured PET during most of the twelve months. In February, measured ET and simulated PET were similar; however, during November measured ET actually was slightly higher than simulated PET. Monthly measured ET and simulated PET rates were less during the winter months (January-December), with highest monthly values of PET and ET occurring in May. The temporal patterns of ET and PET for this turfgrass experiment are similar to those reported for other plant species grown in Florida. Ewell and Smith (1992) reported a higher ET value, of 6.8 cm day^{-1}, for pond cypress (*Taxodium ascendens* Brongn.) during April and May. An upper limit of 6 mm day^{-1} has been reported for conifer stands (Whitehead and Jarvis, 1981).

CONCLUSIONS

Multi-dimensional water flow and solute models are often used to investigate alternative management practices for plant systems in agriculture and in forestry. Sensitivity analyses are often performed for long periods of time (several years), where input parameters can vary over several magnitudes. Two of the major input parameters to such models are PE and/or PET. Obtaining long-term data for these two components over a wide range of geographic sites is often difficult. Thus, an analytical mathematical model (ETM) for describing ET and PET was developed for use subsequently as a submodel during water flow and solute transport modeling.

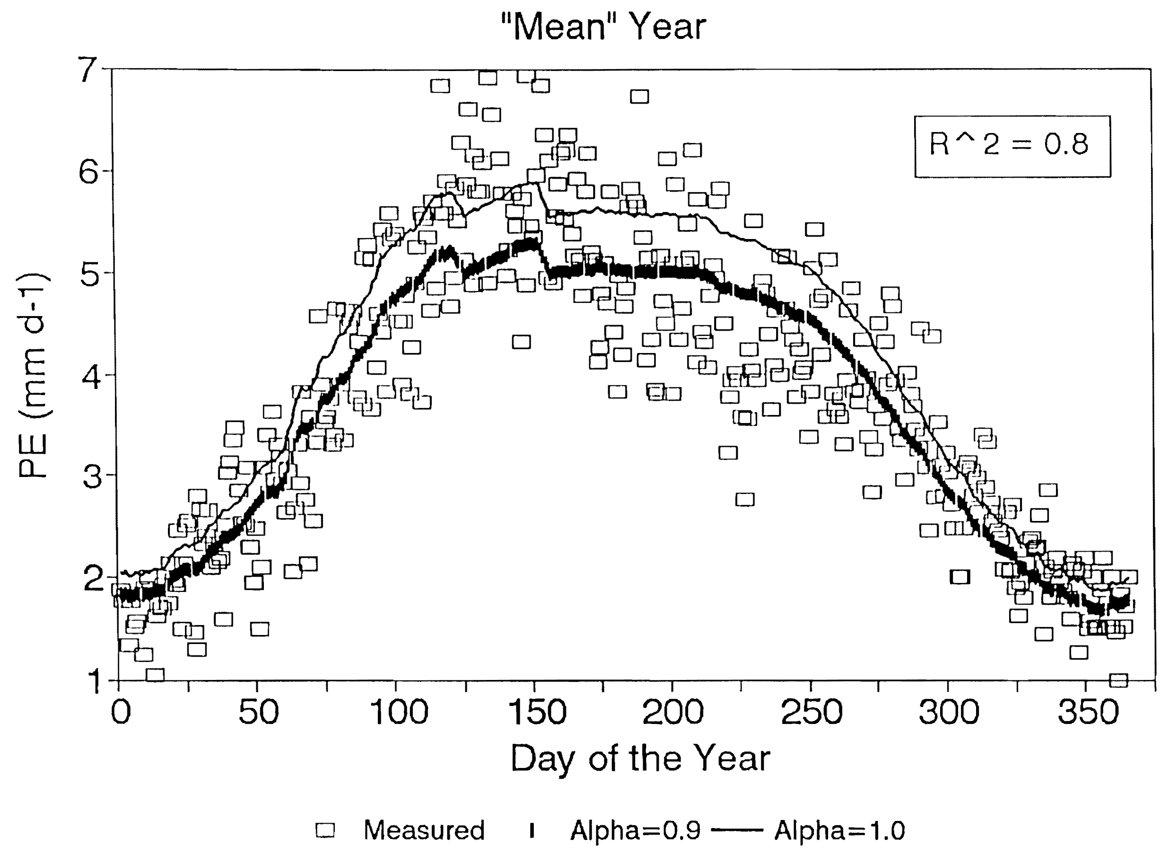

Fig. 6. Measured high PE level, and simulated PE, for a "mean" year at Gainesville, FL.

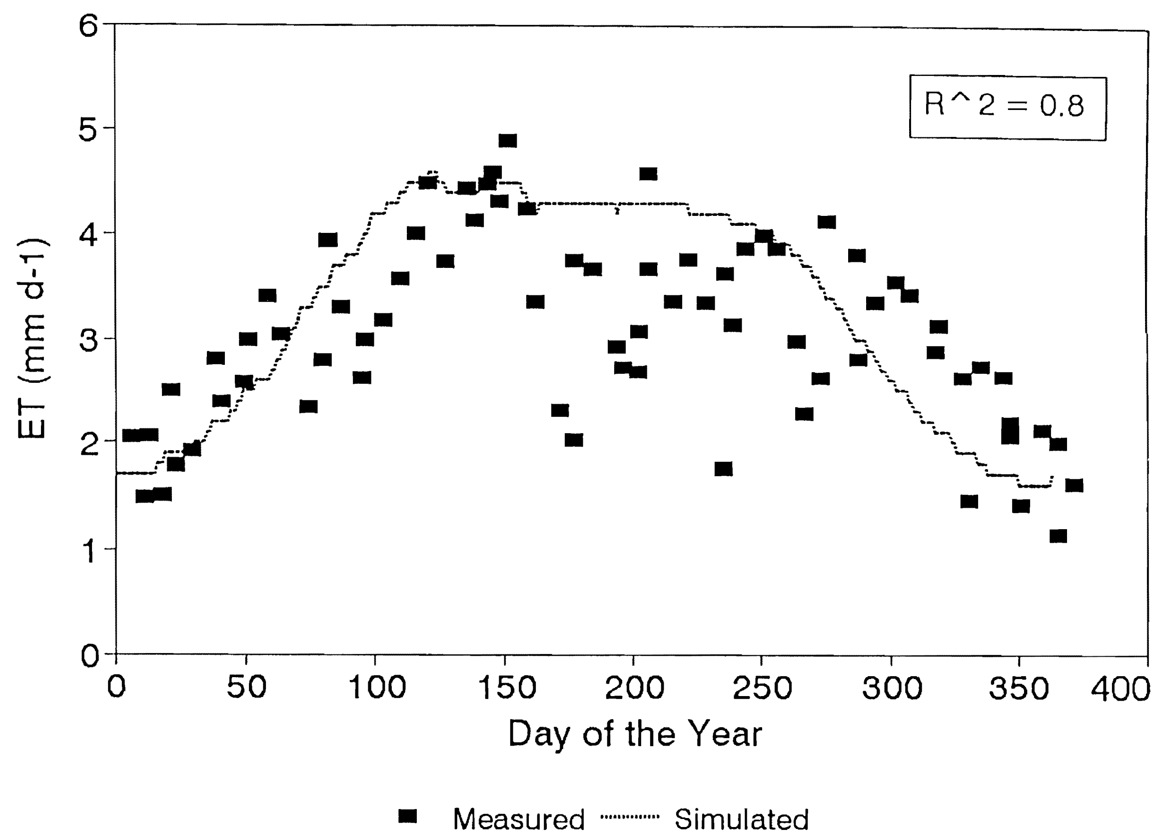

Fig. 7. Measured ET and simulated PET for turfgrass at Fort Lauderdale, FL.

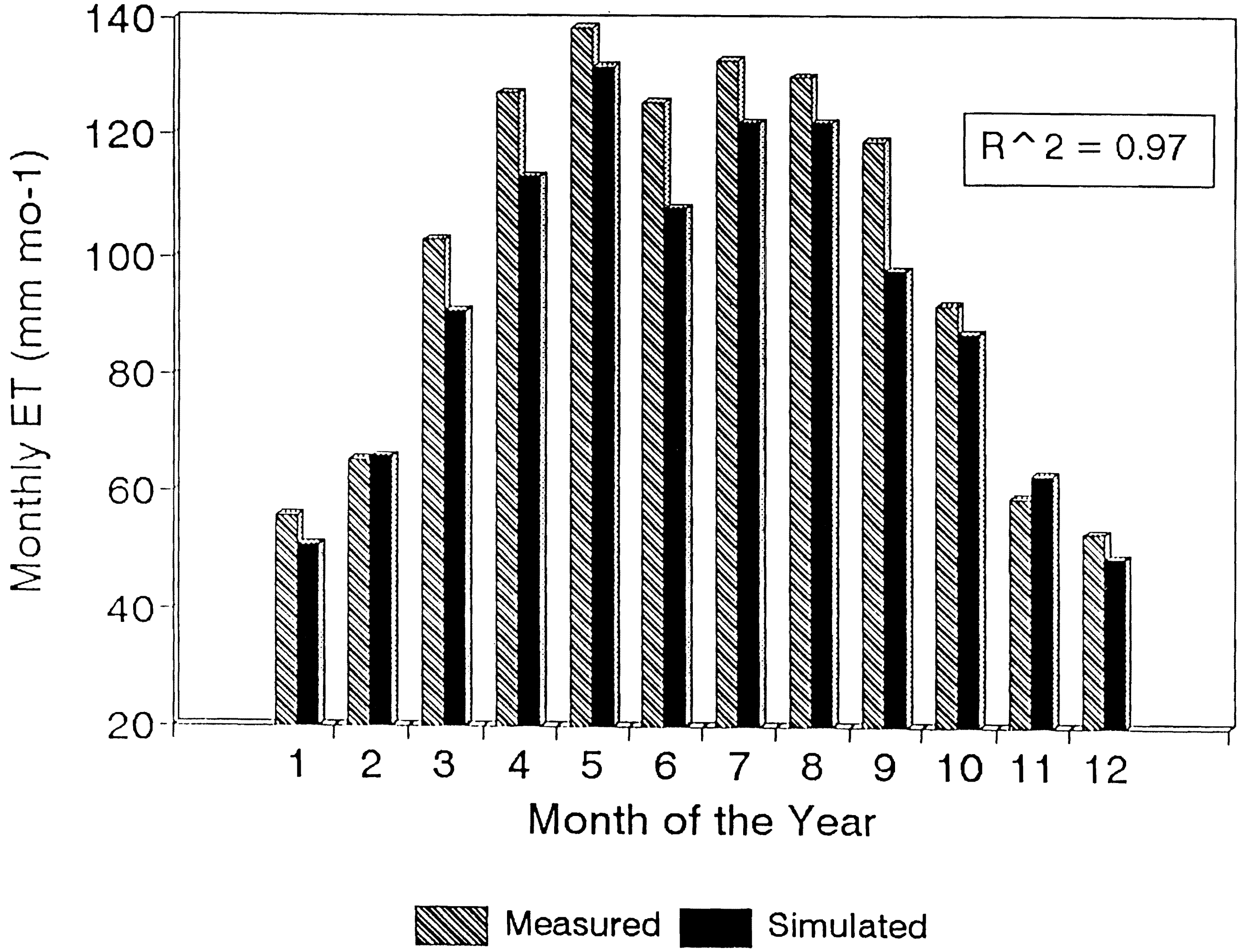

Fig. 8. Monthly measured ET and simulated PET for turfgrass at Fort Lauderdale, FL.

This submodel uses a minimum weather data set typically available for most locations in the U.S. The data set includes minimum and maximum daily temperatures, latitude and altitude values for the location, ratio of actual sunshine hours to maximum possible sunshine hours, day of the year, and reflectivity of the surface. These types of data are readily available and do not require intensive data collection. It is possible, using daily measurements of climatological data at weather stations, to predict PE and PET for different crops. Model predictions of daily extraterrestrial radiation, net radiation, PE, and PET compared favorably to published and measured data. These comparisons substantiate the reliability of our ETM predictions.

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A Model of Coupled Water, Heat and Solute Transport for Mulched Soil Bed Systems

Dilip Shinde*, R. S. Mansell, and A. G. Hornsby

ABSTRACT

Plastic-mulch culture is used extensively in Florida flatwoods and throughout the Coastal Plain of the southeastern United States for intensive vegetable and fruit production. Elevated temperatures are often observed in these mulched beds, which result in a different moisture flow regime compared to unbedded systems (flat bare soil). A numerical model capable of effective description of the coupled processes of heat, water and chemical transport in these soil beds is presented. Application of the model to cases of shallow and deep water tables(WT) of 30- and 120-cm, respectively, confirmed that high temperatures exist under plastic-mulched soil beds. With a WT at the 30 cm depth the soil under plastic mulch was relatively wet compared to the unmulched surface. Preliminary simulations demonstrate the potential for utilizing this model to investigate selected management practices for crops grown in mulched soil-bed systems.

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Plastic-mulch culture is used extensively in Florida flatwoods and the southeastern United States for intensive production of vegetable and fruit crops. The raised soil beds impose topographical nonuniformity that results in differential interception of solar radiation, and plastic mulching allows growers to modify hydro-thermal interactions between the soil and the atmosphere. Higher temperatures are often observed in these mulched beds, which result in a different moisture flow regime compared to unbedded systems (flat bare soil). Thus, mulching may have a significant effect on complex chemical (transport of fertilizer and pesticides) and biological (plant root growth, water uptake by roots) processes important to agricultural production in these soil systems. Mulched, raised, soil bed systems provide improved surface drainage and aeration for crop root-zones under conditions of a shallow water table. Covering of these soil beds with mulch material serves multiple purposes: 1) decreasing leaching losses of applied fertilizers during heavy rainfall events; 2) inhibiting growth of weeds; 3) conservation of soil water by reduced evaporation; and 4) elevation of soil temperatures due to uneven absorption of solar radiation on the mulched beds and bare soil in furrows between the beds. Soil heating usually occurs beneath plastic mulches (Mahrer, 1979, 1980; Mahrer and Katan, 1981; Waggoner et al., 1960), thereby altering the thermal regime of the soil. Alterations in soil temperature also induce changes in soil water and chemical regimes. Heat flow, water flow, and chemical transport are mutually interactive processes which are coupled in soil systems. In this paper, a new multi-dimensional numerical model is presented for describing coupled heat and water (Philip and deVries, 1957) flows and solute transport. The model components are verified using published experimental data. Simple applications are presented to exhibit the potential of the model to investigate the management of mulched soil bed systems.

MODEL DEVELOPMENT

Imposed temperature gradients in soil alter the energy state of water molecules such that water movement may occur. Philip and deVries (1957) and deVries (1958) proposed theory and equations to describe coupled heat and water transfer in porous media in terms of classical mechanisms of vapor diffusion and liquid movement by capillarity, further refined to account for heat flow. Philip and deVries (1957) included the interaction of vapor, liquid and solid phases, and the difference between average temperature gradients in the air-filled pores and in the soil as a whole.

The water-content-based formulation of Philip and deVries (1957) was later modified by Milly and Eagleson (1980), using a pressure-potential-based formulation. The resulting two-dimensional form of a pressure-potential-based formulation of the water flow equation for an isotropic heterogenous medium can be represented as

$$\left[\left(1-\frac{\rho_v}{\rho_L}\right)\frac{\partial\theta_L}{\partial h}\bigg|_T+\frac{\theta_a}{\rho_L}\frac{\partial\rho_v}{\partial h}\bigg|_T\right]\frac{\partial h}{\partial t} =$$
$$\nabla_{xz}[(K+D_{hv})\nabla_{xz}h+(D_{Tv}+D_{Ta})\nabla_{xz}T+Ki]- \qquad (1)$$
$$\left[\left(1-\frac{\rho_v}{\rho_L}\right)\frac{\partial\theta_L}{\partial T}\bigg|_h+\frac{\theta_a}{\rho_L}\frac{\partial\rho_v}{\partial T}\bigg|_h\right]\frac{\partial T}{\partial t}-S$$

where h is the matric potential (m), T is the temperature (°C), t is time (s), x is distance in the horizontal direction (m), z is distance in the vertical direction (m), i is the vertical unit vector, ρ_v is the water vapor density (kg m^{-3}), ρ_L is the liquid water density (kg m^{-3}), θ_a is the volumetric air content (m^3 m^{-3}), θ_L is the volumetric water content (m^3 m^{-3}), D_{hv} is the isothermal water vapor conductivity (m s^{-1}), D_{Tv} is the thermal water vapor diffusivity (m^2 s^{-1} °C), D_{Ta} is the transport coefficient for adsorbed liquid flow due to thermal gradients (m^2 s^{-1}), K is the hydraulic conductivity (m s^{-1}), and S is a sink or source term (m^3 m^{-3} s^{-1}).

Milly and Eagleson (1980) have shown that the heat of wetting can be safely neglected for sandy soils having relatively low specific surface areas. The heat flow equation simultaneously considering convection (heat flow with liquid water flow and water vapor movement) and conduction can be written as

$$\left(C+H_1\frac{\partial\rho_v}{\partial T}\bigg|_h+H_2\frac{\partial\theta_L}{\partial T}\bigg|_h\right)\frac{\partial T}{\partial t} =$$
$$\nabla_{xz}[\lambda\nabla_{xz}T+\rho_L(LD_{hv}+g_aTD_{Ta})\nabla_{xz}h-C_L(T-T_o)q_w]$$
$$-\left(H_1\frac{\partial\rho_v}{\partial h}\bigg|_T+H_2\frac{\partial\theta_L}{\partial h}\bigg|_T\right)\frac{\partial h}{\partial t} \qquad (2)$$

with

$$C = C_d + C_L\rho_L\theta_L + C_v\rho_v\theta_a$$
$$H_1 = [L_o + C_v(T-T_o)]\theta_a$$
$$H_2 = (C_L\rho_L - C_v\rho_v)(T-T_o) - \rho_L W - \rho_v L_o$$

$$W = -j^{-1}g_a\left(h - T\frac{\partial h}{\partial T}\bigg|_\theta\right) \qquad (3)$$

where C_d, C_L, C_v are the specific heats for soil solids, liquid water, and water vapor, respectively (J kg^{-3} °C^{-1}); q_w is the liquid water flux (m s^{-1}); L_o is the latent heat of vaporization (J kg^{-1}) at a reference temperature T_o (°C); L is the latent heat of vaporization at the current temperature (J kg^{-1}), g_a is the acceleration of gravity (m s^{-2}); H is the apparent thermal conductivity (J m^{-1} s^{-1} °C^{-1}); and W is the differential heat of wetting (Edlefson and Anderson, 1943; deVries, 1958) in which j is a conversion factor relating mechanical work to thermal energy (J kg^{-1}).

Non-equilibrium solute transport for a portion of the sorption sites has been incorporated assuming that the solutes may exist in all three phases (liquid, solid, and gaseous). An approach similar to that of Simunek et al. (1992) and Simunek and van Genuchten (1994) has been adopted, which considers that the decay and production processes for solute are different in each phase. The governing equation for solute transport can be written as

$$\frac{\partial\theta_Lc}{\partial t}+\frac{\partial\rho s}{\partial t}+\frac{\partial\theta_ag}{\partial t} = \nabla_{xz}(\theta_LD^L\nabla_{xz}c)+\nabla_{xz}(\theta_aD^g\nabla_{xz}g)$$
$$-\nabla_{xz}(q_wc)-Sc_r-(\mu_L+\mu^\star{}_L)\theta_Lc-(\mu_s+\mu^\star{}_s)\rho s \qquad (4)$$
$$-(\mu_g+\mu^\star{}_g)\theta_ag+\gamma_L\theta_L+\gamma_s\rho+\gamma_g\theta_a$$

where c is the solution concentration (kg m^{-3}); s is the adsorbed concentration (kg kg^{-1}); g is the gas concentration (kg m^{-3}); μ_L, μ_s, and μ_g are the first-order rate constants for solutes in the liquid, solid, and gas phases, respectively (s^{-1}); γ_L (kg m^{-3} s^{-1}), γ_s (kg kg^{-1} s^{-1}), and γ_g (kg m^{-3} s^{-1}) are zero-order rate constants for the liquid, solid, and gas phases, respectively; ρ is the dry soil bulk density (kg m^{-3}); S is a sink term in the water flow equation; c_r is the concentration of solute in the sink term; D^l is the dispersion coefficient for the liquid phase (m^2 s^{-1}); and D^g is the diffusion coefficient for the gas phase (m^2 s^{-1}). The subscripts and superscripts L, s, and g correspond with the liquid, solid, and gas phases, respectively; and $\mu_L\star$, $\mu_s\star$, and $\mu_g\star$ are first-order rate constants for solutes in the liquid, solid, and gas phases, respectively (s^{-1}).

The latter provide the connection between individual solute species in a chain.

The equations for other species occurring in a sequential chain, e.g. for nitrogen, can be written in similar fashion (Simunek and van Genuchten, 1994). The various zero- and first-order rate constants in Eq (4) can be used to represent a variety of reactions or transformations including biodegradation, volatilization, and precipitation.

The concept of multiple reaction sites on soil surfaces is adopted from van Genuchten and Wagenet (1989), where sorption sites are divided into two fractions as

$$s = s^e + s^k \tag{5}$$

Sorption on the first fraction, s^e, is assumed to be instantaneous, while sorption on the remaining fraction, s^k, is assumed to occur kinetically. A non-linear adsorption isotherm relating c and s at equilibrium can be described by the empirical equation

$$s = \frac{\xi C^{\beta}}{1 + \eta C^{\beta}} \tag{6}$$

where ξ, ß, and η are empirical constants. The Freundlich, Langmuir, and linear adsorption equations are each special cases of Eq (6). When ß = 1, Eq (6) becomes the Freundlich equation, and when both ß = 1 and η =0, Eq (6) results in a linear adsorption isotherm. The transfer of mass from the solution to the kinetic sites can be described by a first-order process and mass balance can be written as (Toride et al., 1993)

$$\frac{\partial s^k}{\partial t} = \omega\left[(1-f)\frac{\xi c^{\beta}}{1+\eta c^{\beta}} - s^k\right] - \mu_s s^k + (1-f)\gamma_s \tag{7}$$

where ω is the first-order rate adsorption constant (s^{-1}) and f denotes the fraction of sites which are instantaneously equilibrated.

Solute equilibrium concentrations in the gaseous phase g and in the aqueous phase c can be related by

$$g = k_g c \tag{8}$$

where k_g is an empirical constant equal to $(K_H R T^A)^{-1}$ (Stumm and Morgan, 1981), K_H is the Henry's Law constant (kg s^2 kg^{-1} m^{-2}), R is the universal gas constant (kg $m^2 s^{-2}$ $°K^{-1}$ kg^{-1}) and T^A is the absolute temperature (°K).

The dependency of diffusion, zero-order production, first-order degradation, and adsorption coefficients may be expressed by the Arrhenius equation as (Stumm and Morgan, 1981; Simunek and Suarez, 1993)

$$a_T = a_o \exp\left[\frac{E(T^A - T^A_o)}{RT^A T^A_o}\right] \tag{9}$$

where a_o and a_T are the values of the respective coefficients at a reference absolute temperature T^A_o and absolute temperature T^A, respectively; and E is the activation energy of the reaction or process (kg $m^{-2} s^{-2}$ kg^{-1}).

BOUNDARY CONDITIONS

Boundary conditions for the joint solution of equations (1) and (2) may be a specified value of matric potential and temperature (Dirichlet), a specified water and heat flux (Neumann), or a combination of the two (Cauchy). A similar requirement is needed to solve the solute transport equation (Eq 4).

In mulched soil bed systems the atmospheric boundary is of special concern due to the uneven surface of the soil and the existence of plastic mulch over the bed. Ham and Kluitenberg (1994) reported absorptance, reflectance, and transmittance values on the order of 0.96, 0.03, and 0.01, respectively, for black plastic mulch. Corresponding values for a clear plastic mulch were reported to be 0.05, 0.11, and 0.84, respectively. Van Bavel and Hillel (1975, 1976), Horton et al. (1984), and Chung and Horton (1987) described a procedure for partitioning incoming solar radiation into energy for evaporative water flux and energy for sensible heat flux on bare and mulched soil surfaces, based on atmospheric data. The energy balance was estimated iteratively to obtain the upper boundary conditions at every time step during the simulation.

NUMERICAL APPROACH

The Galerkin-type finite-element numerical method provides the ability to include non-uniform soil properties and non-uniform boundary conditions for the solution of the governing equations over a cross-section of a soil bed. Due to the non-uniform surface geometry of mulched soil-bed systems, triangular elements were used. The lumping technique was used for coefficient matrices of time-derivative terms to obtain numerical stability. A complete description of the finite-element method, basis function derivation, and integration techniques across the elements are presented elsewhere in Istok (1989) and Segerlind (1984). The time-derivative integration of the state variables h, T, and c was achieved through a finite-difference, fully implicit, numerical method.

MODEL VERIFICATION

Verification is required for any numerical model to ensure that the governing equations describe the processes correctly and that the computer code is correct and free of numerical instabilities. Due to the highly non-linear nature of the three governing equations (Eqs 1, 2, and 4), no analytical solution exists at present. Hence, it is not possible to test the complete model directly. However, model sub-components such as water flow, heat flow, and solute transport were tested individually against observed data obtained from the published literature.

The water flow sub-component model was compared with laboratory-measured data for transient water transport through sand as reported by Haverkamp et al. (1977). The influences of heat and vapor transport were ignored. Haverkamp et al. (1977) reported K_{sat} (saturated hydraulic conductivity), θ_s (saturated water content), θ_r (residual water content), and ρ to be 0.34 (m h^{-1}), 0.287, 0.075, and 1.66 kg m^{-3} respectively. A van Genuchten analytical model (van Genuchten, 1980) fit to the water content versus matric potential data provided the parameters (α and n) to describe the hydraulic relationships for sand. A uniform initial water content of 0.10 was specified and water content at the 0.70 m depth was kept constant at the same value. A constant water influx of 0.1369 m h^{-1} was specified at the top boundary. Simulated numerical results for water front movement are compared with experimental data from Haverkamp et al. (1977) in Fig. 1. The model described the movement of the water front well.

Next, the heat flow sub-component model was verified with field-measured data (Chung and Horton, 1991) of temperature for a Nicollet clay loam soil profile with a bare surface located near Ames, IA. The effect of water flow was ignored. Representative values of heat capacity and thermal conductivity for loam soil were used. Initial conditions were taken from Chung and Horton (1991), and temperature at the 0.60 m depth was held constant at 20°C. The observed reported temperature was used as the surface boundary condition. One-dimensional numerical results (Fig. 2) for the 0.05 and 0.15 m soil depths provide a good representation of the observed temperature profile.

Lastly, the solute transport model component was tested against data reported by van Genuchten (1981) for the movement of a pulse of boron (H_3BO_3) during steady water flow through a column of Glendale clay loam. The solute transport parameters (Simunek and van Genuchten, 1994) used were D^{l} = 20.42 × 10^{-5} m^2 h^{-1}, θ_s = 0.445, ρ = 1.222 kg m^{-3}, ξ = 1.14 m^3 kg^{-1}, ß = 1.0, η = 0.0, f = 0.47, and ω = 1.33 × 10^{-2}. The initial concentration was zero and a pulse of 121.44 h duration having a boron concentration of 20.0 mmol$_c$ L^{-1} was applied at a constant flux of 7.13 m h^{-1}. Assuming two-site chemical non-equilibrium sorption, a simulation was run for 20 pore volumes. A comparison of numerical and experimental results (Fig. 3) verified that the model described the transport process with reasonable accuracy.

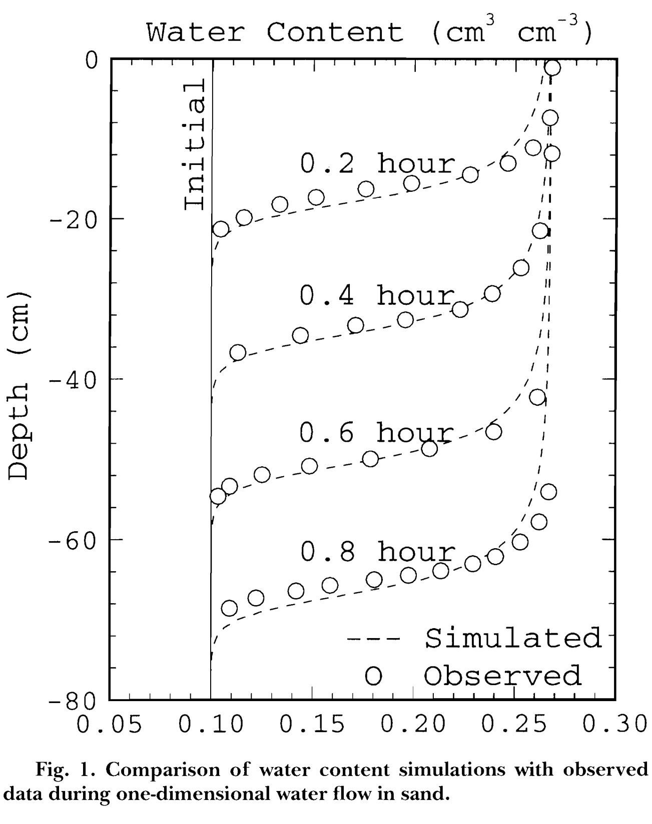

Fig. 1. Comparison of water content simulations with observed data during one-dimensional water flow in sand.

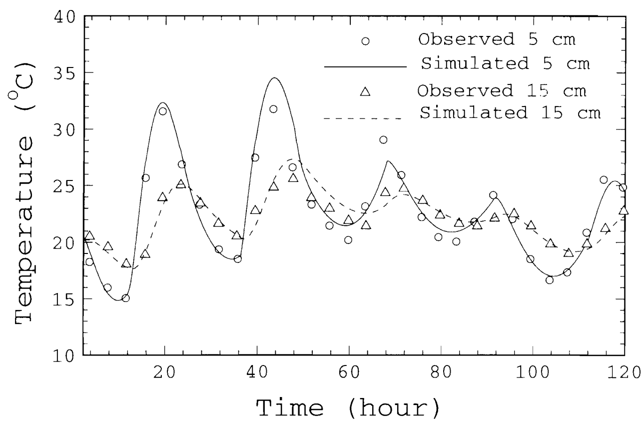

Fig. 2. Temperature comparison of simulated and observed data for one-dimensional heat flow in Nicollet clay loam.

APPLICATION

The model was applied to investigate the influence of water table depth upon heat and water flows in mulched and non-mulched soil beds. Lakeland fine sand soil with uniform properties was considered for these scenarios. Representative average soil properties as reported by Dane et al. (1983) (K_{sat} = 9.63 × 10^{-3} m day^{-1}, ρ = 1.59 kg m^{-3}, θ_s = 0.40, θ_r = 0.08, sand = 91.2%, clay = 7.0%, and organic matter = 1.8%) were used for numerical simulation. Typical weather parameters for the months of June and July in Gainesville, FL (average temperature = 26.86°C, temperature amplitude = 6.13°C, sunshine hours = 14, global radiation = 42.00 MJ m^{-2}) were used. Heat capacity and thermal conductivity were estimated in the model according to deVries (1963). One half of the vertical cross-section of a single mulched bed of uniform soil was considered and bed symmetry was assumed. A schematic diagram of two dif-

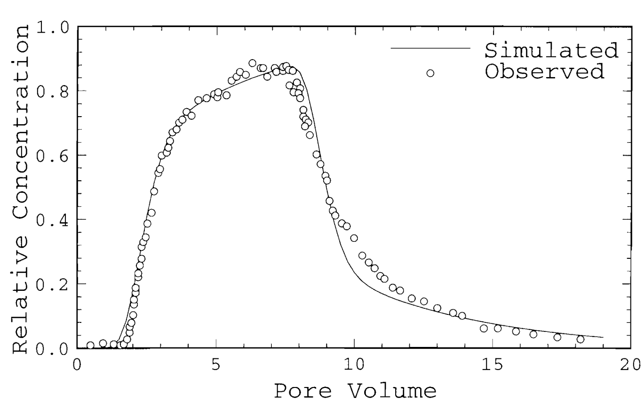

Fig. 3. Observed and simulated breakthrough curve for boron in Glendale clay loam.

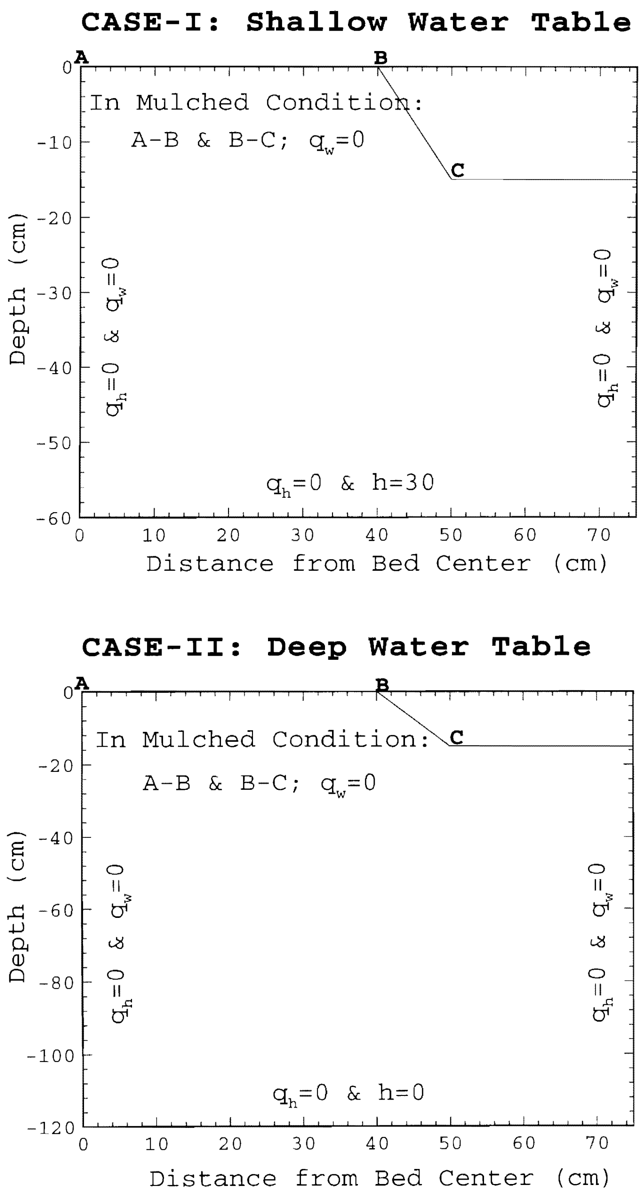

Fig. 4. Schematic for the soil bed system and boundary conditions for different scenarios.

ferent water table conditions—30 cm and 120 cm depth below the soil bed—along with boundary conditions for the governing equations, is presented in Fig. 4. In all cases the initial temperature for the soil was uniform at 22.5°C and the matric potential was specified by a condition of hydrostatic equilibrium with the water table. Simulations for coupled heat and water flow were made for 4 days of diurnal solar radiation and sinusoidal temperature variation about the mean air temperature at the soil surface. Only results for the fourth day are presented.

Case I: Shallow Water Table

Spatial distributions of temperature and moisture content (liquid water + vapor water) for a mulched soil bed with a shallow water table condition are shown for 3 different times after 4 days of solar radiation (Fig. 5). The initial hydrostatic equilibrium was clearly disturbed by non-isothermal conditions imposed by 4 days of sinusoidal temperature variation at the surface due to solar radiation. Simulated soil temperature distributions showed a time lag for sinusoidal temperature behavior. Temperatures in the soil directly under the mulch were higher as compared to the bare soil surface. Under non-mulched conditions (simulation results not shown), the temperature remained uniform across the surface soil layer. Volumetric water under the mulched bed remained high (Fig. 5), due to accumulation of water vapor as compared to the non-mulched (simulation results not shown) soil bed. The shallow water table condition kept soil in the bed wet due to water vapor movement. Consequently, relatively high evaporation rates occurred in the unmulched soil furrows.

Case II: Deeper Water Table

Spatial distributions of soil temperature were similar (simulation results not shown) to those for Case I, but the degree of water saturation of the soil bed was very low due to increased drainage from a deeper water table. Also, in this case soil under the mulched bed had higher water contents than at the bare surface. Water content in the unmulched bed was at the residual level ($\theta_r = 0.08$) near the surface most of the time. A deeper water table also limited evaporation rates at the soil surface due to lower supply rates of water through vapor flow.

Application of the numerical model to these scenarios highlights the importance of coupled water and heat flow in mulched soil-bed systems. Depths to the water table had a significant effect upon distribution of both temperature and moisture in space and time. Consideration of coupled phenomena is important, since both soil heat capacity and soil thermal conductivity are affected by soil water content, and water can move in both the vapor and liquid phases. If isothermal conditions were imposed for model simulations of mulched soil bed systems, results would obviously be limited because no accounting would occur for upward movement of water as vapor flow. Favorable moisture status as well as optimum thermal regime in these soil beds can be maintained by managing the water table depth.

CONCLUSIONS

A new model for coupled heat, water and solute transport was developed and model components were verified using experimental data from the literature. Application of the model to investigate coupled heat and water flow in a mulched soil bed system demonstrated that water table depth dramatically influenced spatial and temporal distributions of temperature and moisture profiles. The utility of the model for visualizing the coupled phenomena of heat and water flows in mulched soil beds was demonstrated. Such information is practically useful to the management of soil bed systems. Although the model was applied to isotropic homogenous cases, it is fully capable of describing

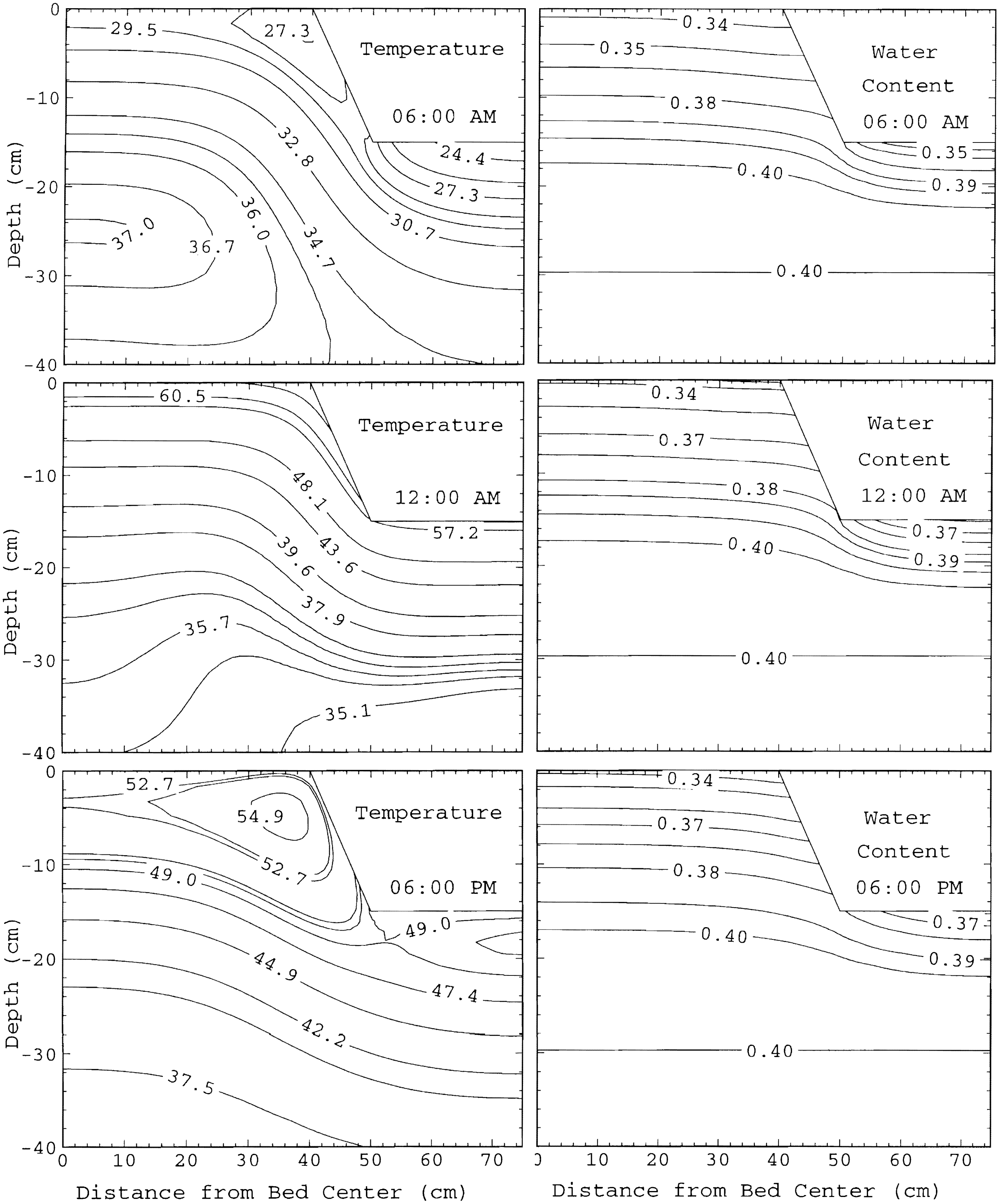

Fig. 5. Temperature (°C) and water content ($m^3\ m^{-3}$) profile under mulched conditions for the shallow water table (30 cm) case at different times on day 4 of the simulation.

heterogenous medium (layering, etc.). The model also holds promise for investigating existing management practices in soil-bed systems and for testing modified management for optimizing agricultural and plant requirements in such systems. The impact of coupled heat and water flow upon chemical flow and vaporizing chemicals will be analyzed in future investigations.

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Hydrological Aspects of Cypress Wetlands in Coastal-Region Pine Forests and Impacts of Management Practices

Ali Fares*, R. S. Mansell, and N. B. Comerford

ABSTRACT

Hydrology for cypress pond/flatwood pine (CPFP) systems located in coastal regions of the southeastern USA is a primary driving force influencing ecology, land development, and persistence of CPFP systems. Water budget analysis provides a means to quantify water entering, undergoing storage in, and leaving such systems. Precipitation, evapotranspiration, ground water, surface water and water storage in the vadose zone represent the main components of CPFP water budgets. Precipitation is considered the main water inflow component, and ET is the major pathway of water consumption, with ground and surface waters being dynamically connected. Alternative silviculture management practices such as establishing unharvested buffer zones, and partial harvesting, should be tested in flatwood pine forests. However, field experiments involving these alternative scenarios are costly and time-consuming. Mathematical models can be used to lessen the number of required field experiments and to investigate important parameters and variables that most influence this system. A need exists for multi-dimensional mathematical models to describe water flow and solute transport for transient flow in a variably saturated media, such as the model WETLANDS. These models can be used to simulate the dynamic connection between free water in ponds and subsurface water in surrounding flatwood forests. The models should include temporal and spatial plant uptake of both water and solutes. This paper gives an overview of the hydrology of CPFP systems, along with current and alternative management practices utilized for these environments. This type of information is helpful for field hydrologists, mathematical modelers working on such systems, and regulatory agencies dealing with these environments.

Wetlands, as defined by the U.S. Fish and Wildlife Service, are lands transitional between terrestrial and aquatic systems where the water table is usually at or near the surface or the land is covered by shallow water (Mitsch, 1979). Zoltai (1988) pointed out that two important hydrologic factors, climate and topography, interact to explain the existence of wetlands in any given landscape. Depressions collect water, level areas do not have enough slope to create appreciable runoff, and low areas including floodplains have runon water from adjacent uplands in addition to periodic flooding.

Cypress (*Taxodium ascendens* Brongn.) ponds, also called cypress swamps, are permanently wet depressions in the landscape. These types of wetlands are numerous in the flatwoods of much of the lower Atlantic and Gulf Coastal Plain provinces of the southeastern USA (Crownover et al., 1995). Improved understanding of the complex hydrology of cypress ponds and adjacent flatwood pine areas is a prerequisite to quantifying the impact of management practices on these systems. The use of vegetative buffer zones or riparian strips has been suggested to provide environmental protection for these wetlands. Such buffer zones can be created by leaving unharvested trees around individual cypress ponds during the harvest of mature pine forests.

Cypress swamps and cypress swamp hydrology have been the focus of several field investigations. Some of these studies have targeted the use of cypress swamps as wastewater treatment areas (Ewel and Odum, 1984; Gillespie, 1976; Heimburg, 1976). Other field studies have addressed the magnitude of ET from the ponds and the impact of clearcutting on ET of the local area (Ewel and Smith, 1992). This paper presents: i) a comprehensive review of the hydrology of the cypress pond flatwood system, and ii) initial synthesis of information about current and alternative management practices proposed for such systems.

HYDROLOGY OF CYPRESS POND/FLATWOOD PINE SYSTEMS

Determining water budgets for wetlands is an imprecise task because of the difficulties associated with determining each of the associated components and because of the climatically controlled temporal variability of wetland hydrology (Carter, 1986). A major problem lies with how well the individual inputs, outputs and changes in storage can be measured or estimated, along with the magnitude of associated errors (Carter et al., 1979; Winter, 1981). For some wetland studies, only a single water-budget component may be measured or estimated.

Water entering, undergoing temporary storage, and leaving a cypress pond flatwood pine system can be quantitatively expressed in terms of a water budget (Hyatt and Brook, 1984) (Fig. 1). The relation of water volume changes in a pond to changes in water budget components for the system per day can be expressed (Heimburg, 1984) as follows:

$$\frac{\Delta V}{\Delta t} = P_P + P_S - ET_P - ET_S + \Delta S_{S/U} + RO \qquad (1)$$

where: P_p = rate of net rainfall falling on the pond (M^3T^{-1}); P_s =rate of net rainfall falling on the flatwood area (M^3T^{-1}); ET_p = rate of ET losses from the pond (M^3T^{-1}); ET_s = rate of ET losses from the flatwood (M^3T^{-1}); t = time period during which the mass balance was calculated (T); $\Delta S_{S/U}$ = the variation of combined water storage in the groundwater and vadose zones (M^3T^{-1}); RO = rate of surface runoff into (+) or out of (-) the system (M^3T^{-1}); and V = the volume of the pond filled with water (M^3). Some of the components of a cypress pond flatwood water budget as measured in the field are summarized in Table 1.

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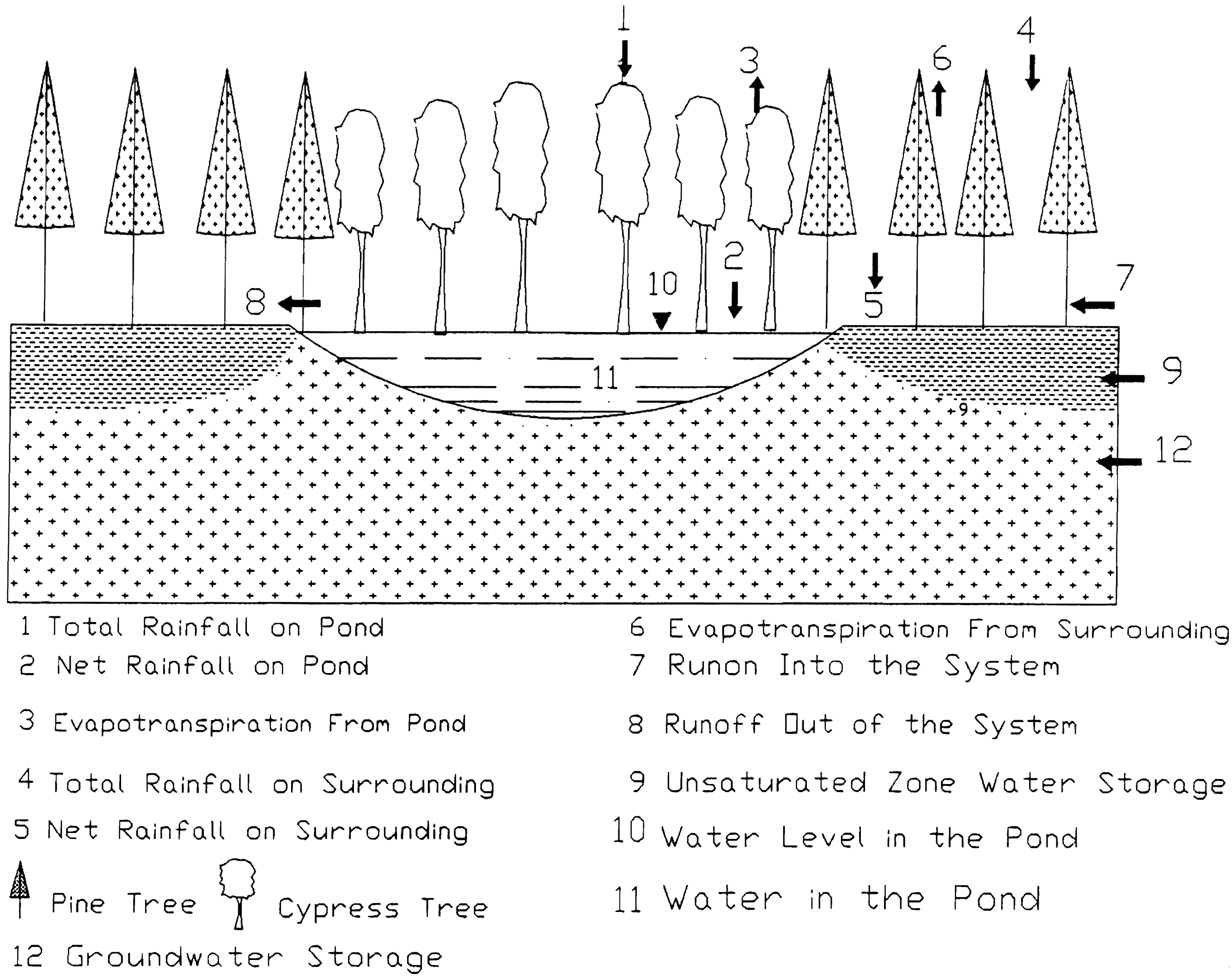

Fig. 1. Hydrological components for cypress pond flatwood systems.

Precipitation

More than half of the average annual rainfall (1370 mm) in north central Florida occurs during the summer months. Minimal and maximal average monthly rainfall amounts occur during November (44 mm) and August (208 mm), respectively. Long-term average monthly rainfall amounts and yearly percentages are presented in Fig. 2. Rainfall in north Florida can be extremely variable from year to year, with standard deviations as great as 40 percent of the mean (Dohrenwend, 1978). Rainfall accompanying frontal (predominantly winter) storms is usually less intense than that associated with convective (e.g. summer) activity, and tends to be more effective for recharge of soil and near-surface groundwater because surface runoff tends to be minimized at this time of year.

Total rainfall falling directly on a cypress pond represented approximately 44% (960 mm) of total water received by the pond (Heimburg, 1976). One-fourth of the total rainfall was intercepted by vegetation and lost directly to the atmosphere; thus, 720 mm of the total annual rainfall typically entered the pond as net rainfall.

Precipitation Interception

In the initial stages of interception by a dry canopy, much of the rainfall is retained. There appears to be a fairly well-defined storage capacity for any given canopy and, when this is exceeded, further intercepted rainfall (net precipitation) either drips from the canopy or runs down the branches and stems. The difference between gross and net precipitation is designated as "interception loss".

Heimburg (1984) found that interception by mature pond cypress typically averages 25% of the total rainfall. This is considerably higher than the 12% recorded for north Florida slash pine plantations by Voss (1975). In North Carolina, interception was 13% of the incoming rainfall for a 10-year-old loblolly pine (*Pinus taeda*) stand (Helvey, 1967). The percentage of rainfall intercepted increases with increasing plant ground coverage as measured, for example, by the leaf area index; thus, the intercepted rainfall by white pine in North Carolina increased to 16% for a 35-year-old stand and to 22% for a 60-year-old stand (Helvey, 1967). Waring et al. (1981) found that interception is generally higher for

Table 1. Field-measured magnitudes for some of the water balance components of the Cypress Pond/Flatwood Pine system.

	Rainfall (cm)			Evapotranspiration (cm)			Runoff (cm)	
Study	Total	Net	Interc.	Pine	Cypress	Mean	In	Out
Heimburg (1976)	107	77	30	n/a	n/a	97	51	0
Riekerk (1989)	128	108	20	n/a	n/a	111	n/a	n/a
Ewel & Smith (1992)	142	66	n/a	n/a	n/a	n/a	n/a	n/a
Riekerk et al. (1995)	114	93	20 pine 23 cypress	89	97	93	n/a	n/a

conifers (e.g. pines) than for deciduous forests, (e.g. cypress). In a recent field study conducted in north central Florida, Riekerk et al. (1995) reported that canopy rainfall interception by an enclosed cypress wetlands was 521 ± 11 mm, or 41% higher than for an open pine stand.

Evapotranspiration

Because cypress trees are deciduous, appreciable transpiration does not occur during the winter months. Bushes, vines and other undergrowth species also contribute to ET, however. Thus, water flow paths in the vicinity of cypress ponds are complex over time and space. During wet seasons (June-September), cypress ponds are recharged both by direct rainfall and by subsurface flow from surrounding pine flatwoods. During dry seasons, however, subsurface water moves laterally from the pond to the surrounding pine flatwoods, where a high ET demand remains.

In Florida, ET for slash pine (*Pinus elliottii* var. Engelm.) has been estimated at 100 cm yr^{-1}, or 80% of annual

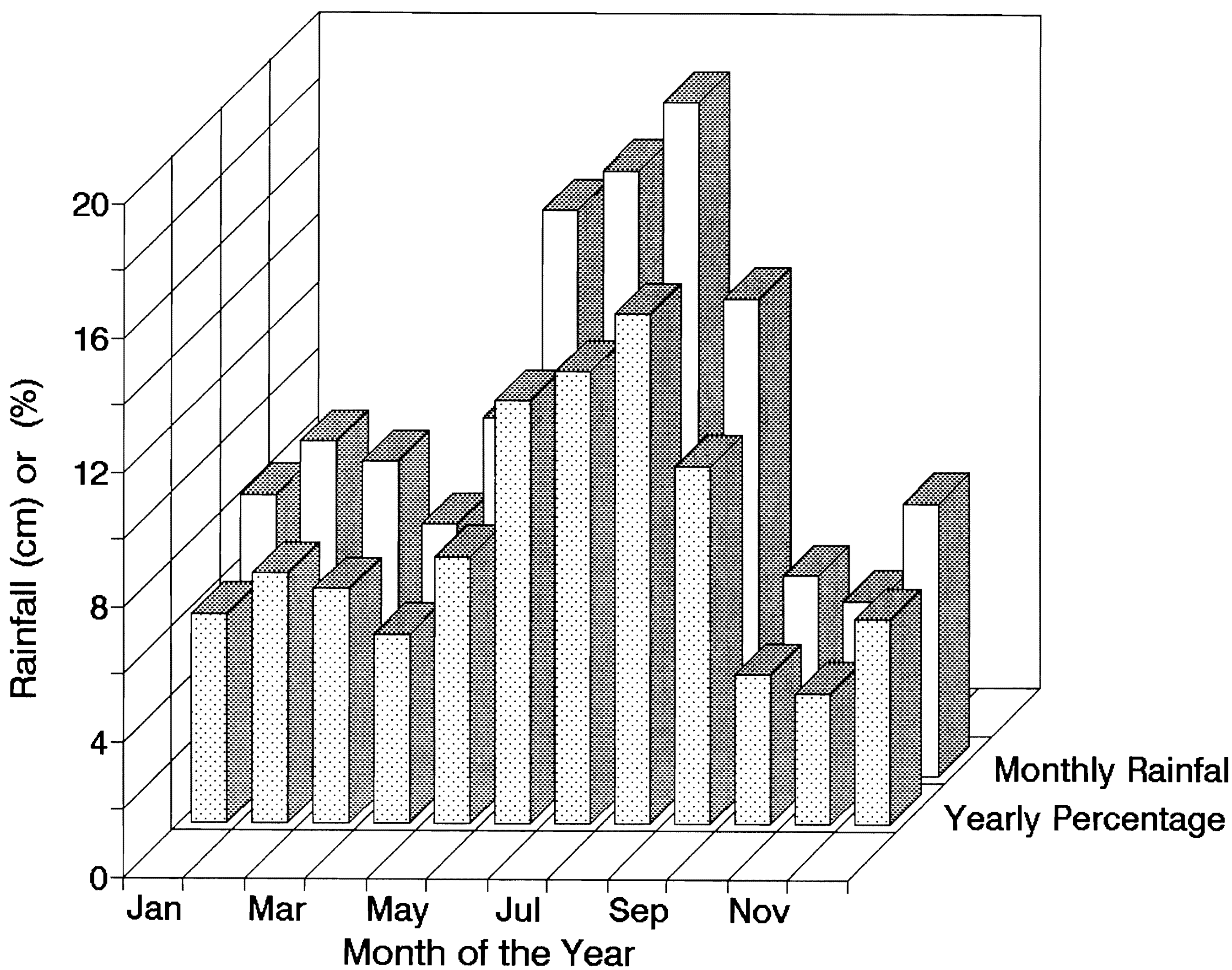

Fig. 2. Monthly rainfall and yearly percentage for Gainesville, FL.

rainfall (Riekerk, 1992). Golkin (1981) reported that estimates of transpiration from cuvette-based measurements in a 25-year old pine stand reached 110 cm yr^{-1}. If 20 cm yr^{-1} is added for canopy interception (Riekerk and Korhnak, 1984), total ET amounts to 130 cm yr^{-1}. Using a weighing lysimeter, Riekerk (1985) found the average ET for a young pine tree to equal 108 cm yr^{-1}, or 84% of annual rainfall.

Brown (1981), using cuvette-based transpiration plus surface water evaporation measurements in cypress wetlands, calculated cypress ET at 108 cm yr^{-1}. Canopy interception, ≈ 15% of the annual rainfall in this case (Ewel and Smith, 1992), was not considered for these calculations. The average ET of cypress after including canopy interception is estimated at 84 cm yr^{-1}, which is less than that of pine flatwoods (Riekerk, 1992). This difference can be attributed to the deciduous and xeromorphic nature of cypress foliage as compared to slash pine needles (Ewel and Smith, 1992). During summer when the cypress trees have their leaves in-place, ET can be as much as 10% less than pan evaporation; in winter, when cypress trees are without leaves, ET can be as much as 50% less (Ewel and Smith, 1992).

Riekerk et al. (1995) conducted a cuvette-based ET study of an upland slash pine plantation with embedded pond cypress. They found that annual ET by both forest types ranged from 54 to 95% of annual rainfall, and averaged 82 ± 8%. Their data showed little difference in specific transpiration by the two major tree species.

Evaporation of Intercepted Rainfall

Coverage of the land surface by vegetation increases surface roughness and enhances eddy transport of heat and water vapor near the surface. Because of this physical effect, evaporation of intercepted rain occurs at rates higher than potential evaporation. Rutter et al. (1975) found that evaporation of water intercepted by pine trees was 3 to 5 times greater than the potential transpiration rate; this rate was in the range 0.2 to 0.5 mm h^{-1} even in cloudy weather or during winter.

Given the high potential ET and rainfall patterns encountered in north central Florida, the time required for evaporation of intercepted rainfall should not interfere materially with the ET of each plant species. However, the amount of intercepted rainfall still should be subtracted from total incoming rainfall when calculating the system's water balance.

Runoff

In a full stand for a dry year, yearly runoff from a cypress pond approaches 0% of the total rainfall; however, the amount of yearly runoff can be as high as 30% of the total precipitation during a wet year (Riekerk, 1989). In north central Florida, runoff was reported to average 240 mm yr^{-1} for a young plantation (Riekerk, 1985). Runoff measured by Tremwel and Campbell (1992) for Spodosols of the Lake Okeechobee Basin averaged 11-22% of total rainfall. Cypress ponds generally are hydraulically interconnected across the landscape, though many are formed in isolated sinkhole depressions (Spangler, 1984). The high hydraulic conductivity of pine-forest surface soils generates little runoff except in saturated zones near cypress wetlands, where runoff pathways may vary depending on the degree of flooding (Riekerk, 1992).

In experimental cypress-pine flatwood watersheds, Riekerk (1992) found that runoff averaged 30% of rainfall where there were no cypress wetlands, 20% where wetland area represented 20% of the total area, and 10% where 50% of the area was occupied by cypress wetlands.

Total or partial harvesting of cypress pond/flatwood systems also increases runoff. The first year following harvest, runoff was reported to increase by 150% (compared to the previous year) due to minimal ET; however, this increase had dropped to 65% six years later (Riekerk, 1989). Runoff occurrence is related as well to storm intensity and to depth of the water table; the more intense the storm and the higher the water table, the more likely that runoff will occur (Heimburg, 1984).

DYNAMIC INTERACTION BETWEEN SURFACE WATER IN PONDS AND SURROUNDING GROUNDWATER

Three major scenarios have been observed in the field for the dynamic coupling of water flow between cypress ponds and the groundwater beneath adjacent uplands. During the first scenario water may flow into ponds from the surrounding area, making the pond a focal point of surface drainage for excess water (Crownover et al., 1995; Sun et al., 1995). In the second case, water level in the pond may be higher than the adjacent upland water table; thus, water may flow away from the pond and irrigate surrounding forest vegetation (Crownover et al., 1995; Heimburg, 1984). In the third scenario, water simply may flow through the pond in response to local topographical gradients (Crownover et al., 1995; Heimburg, 1984; Sun et al., 1995).

During reverse-flow conditions ET provides a driving force for water flow from the ponds into the subsurface of adjacent pine flatwoods. Since groundwater flow typically changes direction seasonally, solute transport also should follow similar patterns. Thus, the hydrology of pond-flatwood systems should greatly influence the potential for contaminant transport into ponds and subsequent drainage runoff between ponds and nearby streams.

Heimburg (1984) observed that surface water levels in cypress ponds tend to fluctuate much less than groundwater levels in adjacent flatwood forests. For example, for each cm of water consumed by ET from a cypress pond, the pond water level would decrease by one cm. In an adjacent pine forest, however, the corresponding decrease in groundwater table depth is roughly equal to the ratio of ET to the average volumetric water content (Θ) of unsaturated soil above the water table. It could be as much as 10-fold greater, and is commonly 3-fold or more. For sandy soils with relatively high hydraulic conductivities under wet conditions, this induced lateral water flow towards and away from ponds can be highly important. For a given value of ET, magnitude of the ET/Θ ratio should increase over time as water table recession occurs between rainfall events, with Θ decreasing concurrently. Thus, water flow paths in the vicinity of cypress ponds are complex both in time and space. The frequency, and spatial and temporal distribution, of rainfall must be considered in any predictions of such paths.

CURRENT AND ALTERNATIVE FOREST MANAGEMENT PRACTICES

Clear cutting of mature (20-25 year-old) pine trees is the conventional method for forest harvest in the southeastern Coastal Plain. Among the controversial aspects of forest clearcutting is the potential for increased water runoff induced by dramatically decreased ET. Nutrient loss, erosion, flooding and subsequent degradation of surface and groundwater quality can result from this sharp decrease in ET. An alternative to clearcutting is progressive strip cutting, a form of clearcutting that can be carried out in several cycles and over a number of years. Designated buffer zones in the transitional area between pond wetlands and flatwood forests can also serve as a practical way for controlling areas contributing to the runoff of water into the ponds. The cypress ponds often can be considered simply as interconnected mini-wetlands that drain Coastal Plain watersheds to local streams during wet periods.

Buffer Zones

Buffer strips include vegetated filter strips (VFT), buffer zones (BZ), or filter strips that provide alternating bands of planted or indigenous vegetation. They provide a means for preventing or at least reducing the transport of sediment, nutrients, and agrochemicals from land management operations into aquatic environments. Buffer strips are also used to mitigate the potential adverse effects of agricultural practices on adjacent surface waters (Comerford et al., 1992).

Buffer zones appear to be generally quite effective in removing soluble nitrogen (N) from water moving through these areas, largely by denitrification. More than 80% of the NO_3-N is commonly removed (Lowrance et al., 1984; Schipper et al., 1989). Phosphorus (P) removal is more variable and generally much less efficient than for N, with a range of removal efficiencies which varies between 0 and 90%. Other plant nutrients have not yet received the attention that N and P have, mainly because they are not considered as important in limiting the production of terrestrial or aquatic ecosystems (Comerford et al., 1992) or in leading to eutrophication of nearby surface streams.

Best Management Practices (BMPs) for Cypress Pond/Flatwood Pine Systems

Because cypress ponds are hydrologically sensitive to forest activities and especially to harvesting, BMPs are used to regulate timber harvesting activities in these locations. Harvested areas are classified at present into three main categories (Florida Dep. of Agric. and Consumer Serv., 1991): i) wetland areas less than 80 ha, ii) wetland areas 80 ha and larger; and iii) units which contain five or more small isolated wetlands, each less than 0.8 ha in size. For the latter category, 20% of the number of isolated wetlands must be retained unharvested until regenerated stands on the other 80% of the area attain an average tree height of at least 6 m (Florida Dep. Agric. and Consumer Serv., 1991).

Regulatory areas called Special Management Zones (SMZ) also have been designated as part of the forest BMPs. These SMZ areas consist of specific areas associated with identified water bodies (lakes, ponds or streams). The purpose of the SMZ is to protect water quality during silviculture operations by reducing or eliminating direct forestry-related inputs of sediment, nutrients, logging debris, and chemicals that could adversely affect the aquatic ecosystem. Each SMZ has a specific width that is prescribed by the size of the associated water body, soil type, and degree of slope for the adjacent uplands.

EVALUATING ALTERNATIVE MANAGEMENT PRACTICES

The impact of intensive forest management practices on water quality and quantity can have both short- and long-term effects. Simultaneously minimizing these detrimental environmental effects on water resources and optimizing forest productivity requires an adequate understanding of the magnitude, timing and duration of hydrological responses to forest activities. Conducting field experiments to assess the long-term effects of pine harvest on the hydrology of cypress pond/flatwood areas is costly in time and resources, site-specific, and can only provide answers primarily over the long-term.

Mathematical models offer practical tools for optimizing two precious assets: time and money (Salama et al., 1993). Modeling endeavors lessen the number of required field experiments and underscore important parameters and variables that most influence such systems. A modeling approach also offers a means to evaluate the relative importance of hydrological and solute-transport processes with advantages of minimizing cost, time, and effort. Once this information is known, future field work can be reduced significantly and realistic quantification of these parameters including overall system response can be estimated. However, results from this approach must not be accepted until rigorous field testing/verification has occurred.

Recently, Salama et al. (1993) used the numerical model MODFLOW (McDonald and Harbaugh, 1988) to predict the effectiveness of different management options applied to catchments in reducing groundwater discharge and water table rise for saline drylands of Western Australia. Results from their simulations revealed that planting 25% of the catchment with deeply rooted trees should effectively reduce groundwater levels and, consequently, reduce saline groundwater discharge. Such predictions agreed with previous studies (Bell et al., 1990; Schofield, 1990) in high rainfall areas which had shown that 25-50% reforestation is required to control groundwater discharge. Location of the trees is also an important factor. Trees planted in recharge areas can reduce recharge into the aquifer through increased interception and evapotranspiration, and can also directly extract water from the water table if their roots are able to reach it.

Modeling the impact of different management practices on the hydrology of cypress pond/flatwood systems requires a multi-dimensional water flow and solute-transport model. This model should be able to dynamically link surface water in ponds with underlying groundwaters in adjacent areas. After extensive search of the literature, the authors were not able to find such a model in-place. Thus, a multi-dimensional water flow and solute-transport modeling effort has been undertaken to simulate a dynamic link between one or more surface water bodies and surrounding subsurface waters (Fares et al., 1993; 1994; 1995). This effort was begun by modifying the VS2DT (Variably Saturated 2-Dimensional Transport) model developed by the U.S. Geological Survey (Healy, 1990; Lappala et al., 1987). Modifications to VS2DT included: i) incorporation of a variable-geometry pond (or ditch) with variable water levels; ii) inclusion of a sub-model to estimate potential evapotranspiration, ETM (Fares, et al., 1995), using the Priestley-Taylor equation and a minimum set of daily weather data including minimum and maximum temperatures, latitude and altitude of the location, and sunshine/cloudiness ratio; iii) ability to incorporate differing plant root distributions; and iv) the possibility of quantifying runoff or stream flow from and into the pond in question.

CONCLUSIONS

A need exists to improve knowledge of wetland hydrology for cypress pond/pine flatwood ecosystems. The hydrology of such ecosystems is dominated by the relatively flat landscape; hence, evapotranspiration and precipitation provide the primary hydrological outputs and inputs, respectively. The high infiltration rates of sandy soils in flatwood pine forests generate little surface runoff even in saturated areas near the swamp. Conventional forest management practices have several controversial aspects, including the potential for increased water runoff induced by decreased ET. This can result in nutrient loss, erosion, flooding, and subsequent degradation of surface and groundwater quality. Alternative harvesting strategies such as progressive strip cutting or leaving designated buffer zones in the transitional zone between pond wetlands and flatwood forests have been suggested as a practical means for controlling water runoff into the ponds.

Conducting field experiments to assess the long-term effects of pine harvests on the hydrology of cypress pond/flatwoods areas is costly in time and resources, is typically site-specific, and requires long periods in order to provide answers. Numerical models offer an alternative approach for predicting the effectiveness of management strategies in controlling water table fluctuations and subsequently minimizing significant movement of contaminants to the local groundwater. A modeling approach offers a means for evaluating the relative importance of hydrological and solute-transport processes with advantages of minimal cost, time, and effort. None of the existent mathematical models appeared capable of fulfilling this duty. Thus, there is need to apply multidimensional mathematical models such as WETLANDS for the purpose of investigating alternative management practices for cypress pond flatwood pine systems in the Coastal Plain. WETLANDS is a multi-dimensional mathematical model that dynamically links the surface water in the pond to the surrounding groundwater. This model includes an ET component (ETM), along with water and solute plant uptake. Subsequent reports will describe components, performance, and predictions using WETLANDS.

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A Graphical User Interface for Real Time Irrigation Control in Greenhouses

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ABSTRACT

A graphical user interface was developed for real-time greenhouse irrigation control using Visual Basic™, which is a visual development language for Windows™. It allows the user to select among three different water management control strategies: 1) closed loop (automated), 2) timer, and 3) manual control. Software engineering focused on developing a product with a friendly user interface, flexible functionality, and hardware independence. The resulting software simplifies specification requirements and user intervention in the controlled system.

Computer technology improvements, coupled with declining costs, have stimulated the development and adoption of control systems in agriculture. Control systems for ornamentals production have been used extensively in Florida (Zazueta et al., 1984; Jacobson et al., 1989; Vellidis et al., 1990; Zazueta and Smajstrla, 1992; Zazueta et al., 1992). It seems that use of these systems is likely to expand rapidly, due to the current trend in adoptions of computer systems by farmers, and also as a result of developments in the agricultural control-system industry.

Phene (1988) discussed computerized management techniques that can be used with irrigation control systems, including: 1) evapotranspiration estimates (either measured, or estimated from meteorological parameters); 2) soil and/or plant water-status monitoring; and 3) dynamic simulation modeling. Implementing one or more of these techniques, using automated irrigation-control systems, has the potential to improve water, energy and chemical use efficiency. This improvement can be achieved by applying water at a high application efficiency and/or by fine-tuning the irrigation scheduling.

A control system consists of a combination of hardware and software that acts as an events supervisor, with the purpose of managing the target operation (Zazueta et al., 1984). The objective of this study was to develop a friendly graphical user interface that, when connected to suitable hardware, is capable of performing real-time automated irrigation control in greenhouses.

GREENHOUSE IRRIGATION

Greenhouse production is affected by many factors, including timely and sufficient water applications. A variety of irrigation systems is used in greenhouse production, including microirrigation, ebb and flow, fog and mist, and sprinkler systems. All such systems attempt to maintain a small volume of plant-growth media at an optimal water potential via relatively small and frequent applications of water. Because crop growth, nutrient transport and disease control are closely related to water deficiency and excess, irrigation management plays an important role in system performance and resulting profit margins.

Different plant-growing activities may occur simultaneously inside a greenhouse, which makes it difficult to have the same irrigation management solution for all purposes. Although this paper emphasizes a system for containerized production, it is possible with only small changes to make the technique applicable to other types of greenhouse growing activities as well.

CONTROL SOFTWARE

The control software consists of a collection of procedures and methods required to specify, maintain, and execute control actions and data inputs. Using an analog source (e.g., sensor input into a data acquisition system), data are collected concerning the system to be controlled. Algorithm or heurestic procedures can then be applied to the data, and other knowledge or operations represented in turn. Subsequently, actions that need to be implemented can be defined. Finally, these actions can be applied using a control interface.

Key to performance of the system is a user interface that allows easy manipulation and maintenance of data in the system. The software described herein provides such an interface. The control software was entirely developed using Visual Basic™, without need for any subroutines in another language. This is an object-oriented language for Microsoft Windows™, which facilitates high-quality software production. In addition, it allows for software design using code that is easy to debug initially, and to maintain.

Control Interface

From the user's viewpoint, the control interface consists of a series of screens (windows) related to different control functions that the user can manipulate. Figure 1 shows the startup screen. At this level, the user can select among one of three different management strategies: automated, manual or timer-controlled, using either the on-screen "push" buttons or the menu bar at the top of the screen.

When the program is launched for the first time and a control strategy is selected, the software will ask the user to configure the control system. A window then is opened which requests a set of configuration parameters that must be defined by the user. Figure 2 shows an example of a configuration screen for an automated-control strategy. The manual and timer-controlled

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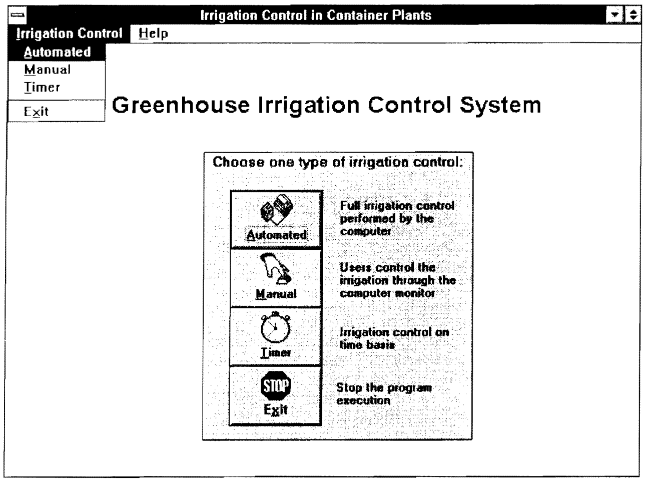

Fig. 1. System startup screen.

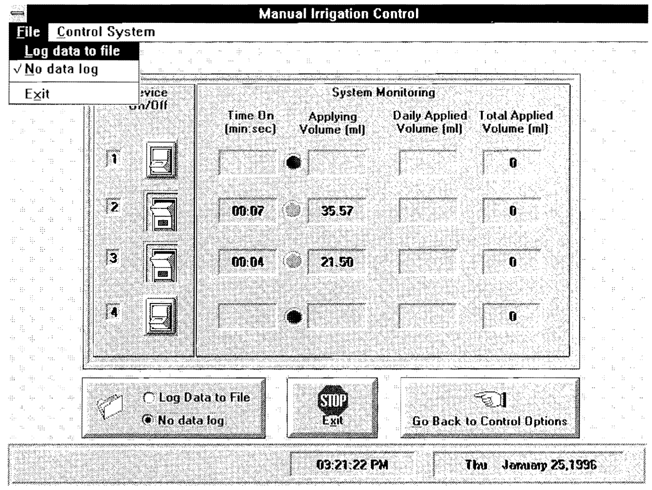

Fig. 3. Manual control-mode screen.

modes use the same configuration parameters, though the automated-control strategy requires that more parameters be predefined. These additional parameters are related to the type of control devices chosen to monitor and manage soil or plant water status.

For the example shown in Fig. 2, the user must define the duration of water application, the sensor delay time, and the lower and upper tension limits of the growth-media moisture range to be maintained in the system. For the prototype version on the University of Florida campus, the interface was designed to use soil tensiometers as sensing devices. The device used in this application was a modified tensiometer developed by Zazueta et al. (1994) to control the water status of containerized plants. In principle, any device that responds monotonically in either increasing or decreasing manner to growth-media water tension can be used.

The prototype version of the interface was designed to allow control of up to four separate irrigation stations. This limit was set in order to address the needs of the greenhouse for which the prototype was field-tested (part of the Fifield Hall greenhouse complex on the Univ. of Florida campus, in Gainesville). The interface can be easily increased via simple computer-code modifications to accommodate *any* number of stations. The main limitation is imposed by available hardware on-site (number of data acquisition ports, solenoid-activated on-off valves and pumps, separate-bench sensor arrays, etc).

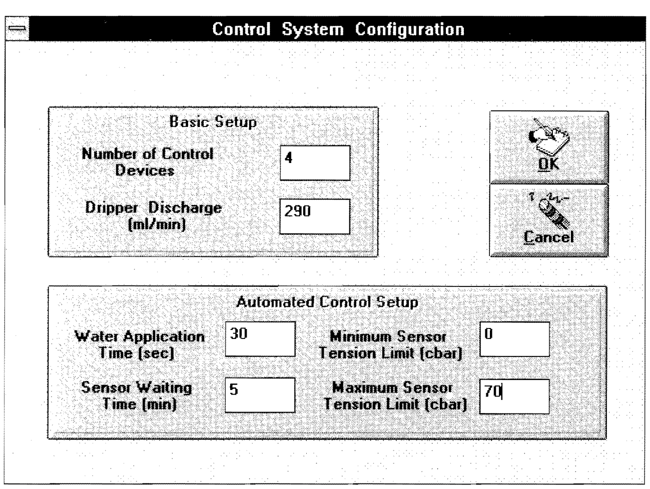

Fig. 2. Configuration screen for the automated-control mode.

Manual Control

For the manual-control strategy, controlled devices (valves, pumps) are actuated using switches on the screen (Fig. 3). This window also displays the time that a controlled device was powered on, and the volume of water applied during the "on" interval. The volume applied is calculated from time and flow rate.

For consistency and ease of use, functionality is maintained throughout the interface. Each main panel (Fig. 2) is divided into two different sections: 1) device control, and 2) system monitoring. The device-control panel allows the user to control operation of all relevant devices. The system-monitoring section allows the user to appraise the day-to-day progress of the operation. In the system-monitoring section, the amount of daily water applied and the accumulated volume since the beginning of the growing season can each be observed. Another common characteristic of each window is the time and date controls at the bottom of the screen.

With all of the irrigation-control windows the user has the option, using the file menu bar or a command button placed at the bottom of the screen, to log the data created by the control into a data file (e.g., in ASCII format) for future or off-site reference. Beneath the main control panel, all control screens also have two additional buttons: **exit** and **return to irrigation control**. The first button stops the program's execution, and the second returns the user to the irrigation-control options.

Timer Control

The timer-control option (Fig. 4) emulates a commercial irrigation timer. The user can create an irrigation schedule by defining a start time, the number of

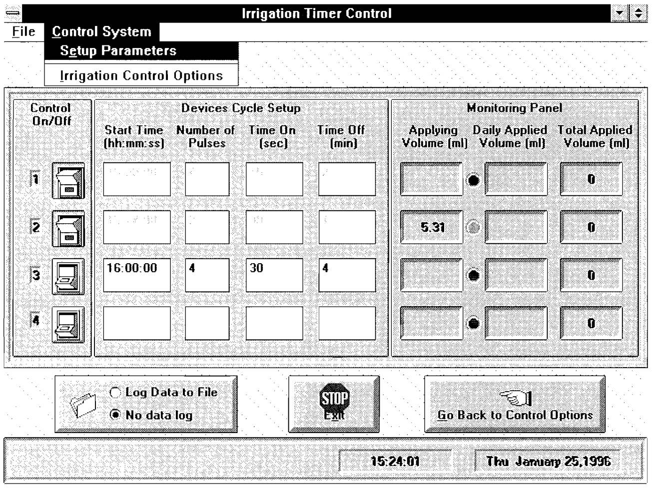

Fig. 4. Timer control-mode screen.

water applications, duration of each application, and a "dead" time between applications. Figure 4 shows an example of an irrigation timer-control window. The software also allows the grower to choose between pulsed or continuous irrigation. In the "setup" section for this window, the user must adhere to a 24-hr time format (hh:mm:ss).

As with the other control windows, the user always has the option of using the menu bar to return to the configuration window and thereby change any system setup parameters from those initially defined.

Automated Control

The automated-control strategy (Fig. 5) uses a closed-loop system that applies irrigation water on demand. Acquired data are used by the computer to decide when to irrigate. With this strategy, the system attempts to maintain a constant soil-moisture level (set point). Figure 5 shows a sample screen for the automated-control mode, which uses one section in the main panel to define sensor set points for each subsystem which is being managed as a unit.

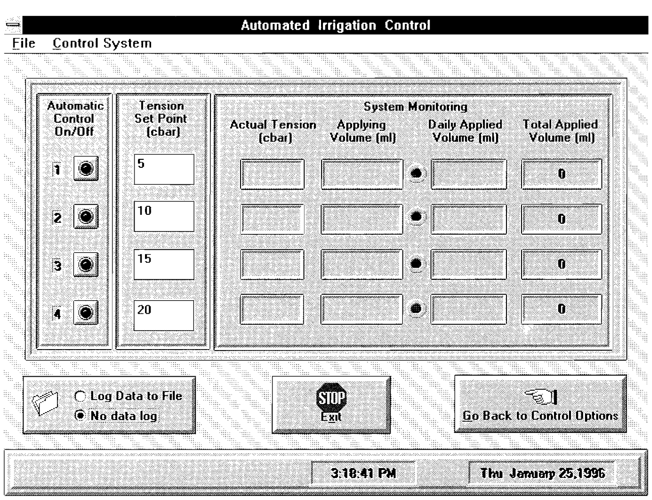

Fig. 5. Automated control-mode screen.

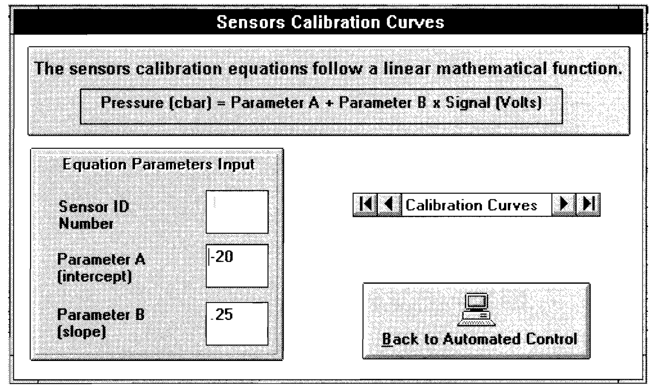

Fig. 6. Window to input sensor calibration curves.

Although this version of the program was designed to use soil tensiometer moisture-sensing devices, *any* appropriate sensor can be used without, or with only minor, changes to the program's source code. Source code is available from Dr. Zazueta upon request, and can then be easily modified by anyone familiar with Visual Basic™ programming commands.

Most sensors require calibration curves, defining the relationship between sensor behavior and growth-media water tension. These parameters are defined in the program as shown in Fig. 6. It is possible to input the calibration-curve parameters for pressure transducers used in the modified tensiometers (Zazueta et al., 1994), or for any *other* sensors with linear response.

Use of the automated irrigation-control option is simple. After the calibration curves and the set points have been entered, the user has only to switch on the automatic control buttons. The system then will read soil water tension at pre-selected intervals, and activate the controlled devices if an irrigation is needed. Using the pre-set values for the media moisture-tension limits, the system includes a routine to check for proper operation of the sensors, so the user is advised immediately in cases of potential system failure.

Interface General Features

To avoid mistakes in actions taken by the user, a number of warnings and error messages have been included in the system as well. Nearly all buttons have message boxes associated with them. In addition, all input variables are formatted in a specific manner, insuring that the user cannot enter any value in non-standard format.

System Requirements

The system requires only an IBM PC-compatible system that runs Microsoft Windows™ 3.1. The system setup diskette provides all of the required files.

CONCLUSIONS

Although this control interface was developed for use with containerized-plant irrigation, it is clear that the system has the desired flexibility for expanded use to control other system parameters as well. The system has the following characteristics:

—a friendly user interface allowing simple definition of tasks, which renders operation details and complexity transparent to the user;

—user-defined hardware configuration, allowing simple specification of the controlled system; and

—ability to use concurrently one of three different irrigation-management control strategies.

Further field evaluations are recommended to demonstrate the full potential of the developed system. Such evaluations should be conducted, wherever possible, at the level of present-day commercial operations.

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SYMPOSIUM

Impact of Crop Management Practices on Soil Nematode Populations

R. McSorley

ABSTRACT

Many methods are available for managing plant-parasitic nematodes in crop production. Nematicides, resistant cultivars, crop rotation, cover crops, organic amendments, biological control, tillage, soil solarization, fallow, flooding, weed management, healthy planting material, and other cultural practices have each been used for managing nematodes in Florida, with varying degrees of success. Research on these practices for managing plant-parasitic nematodes in Florida is reviewed. Prospects and research needs for implementation of alternatives to nematicides are discussed. Compared to fumigation technology, most alternative methods require much more detailed knowledge of nematode biology and ecology for their successful use. If nematicide usage declines in the future, successful crop protection from nematode damage will depend on the ability to obtain more complete biological data and research information for specific regions and crops and on the capability to integrate this information with a combination of available nematode management practices.

Nematode problems in Florida agriculture are well-known (Christie, 1959), and innovative methods for their management have been attempted since early in this century (Watson, 1921). Probably the most significant event affecting nematode management in Florida was the development and widespread use of soil fumigants and other nematicides in the 1950's and 1960's (Noling and Becker, 1994). For many years, production of tomato (*Lycopersicon esculentum* Mill.) and several other vegetable crops in Florida has been dependent on broad-spectrum soil fumigants containing methyl bromide (Overman and Jones, 1985). However, anticipated restrictions on future production and use of methyl bromide have prompted serious interest in a search for alternatives (Noling and Becker, 1994). Chemical alternatives to methyl bromide have been sought and evaluated since the mid-1980's (McSorley et al., 1985; Overman and Jones, 1985). However, the most promising chemical alternatives (nonfumigants and a few fumigants such as metham sodium or 1,3-dichloropropene) have limitations such as reduced efficacy compared to methyl bromide, lack of broad-spectrum activity, or potential environmental hazards (Noling and Becker, 1994).

Numerous non-chemical alternatives are available for managing plant-parasitic nematodes (Duncan, 1991; McSorley and Duncan, 1995; Trivedi and Barker, 1986). Currently, these methods have not been widely adopted by growers as replacements for methyl bromide (Noling and Becker, 1994). Their effects can be less evident than those of methyl bromide and other fast-acting chemical products, which have resulted in drastic reductions of nematode populations and probably produced unusually high expectations about the feasibility of managing nematode problems. In addition, the use of non-chemical alternatives often requires a much more detailed knowledge of nematode biology and ecology than does application of chemical nematicides. Nevertheless, a number of these alternatives have been evaluated in Florida, with varying degrees of success.

RESISTANT CULTIVARS

Many crop cultivars are available with resistance to certain species or races of root-knot nematodes (*Meloidogyne* spp.), which are key pests in many agricultural systems (Cook and Evans, 1987; Fassuliotis, 1982; Sasser and Kirby, 1979). Resistance may be present in many other crop cultivars, but has remained unrecognized because much material has never been screened for response to root-knot or other nematodes. Within the last 10 years in Florida, sources of relative resistance or tolerance to root-knot nematodes have been recognized in some germplasm of alyceclover (*Alysicarpus* spp.) (Taylor et al., 1986), alfalfa (*Medicago sativa* L.) (Baltensperger et al., 1985), desmodium (*Desmodium* spp.) (Quesenberry and Dunn, 1987), clover (*Trifolium* spp.) (Quesenberry et al., 1989), and other forage crops (Taylor et al., 1985); as well as in cowpea (*Vigna unguiculata* [L.] Walp.) (Gallaher and McSorley, 1993), sorghum (*Sorghum bicolor* L.) (McSorley and Gallaher, 1991), oats (*Avena sativa* L.) (Opperman et al., 1988); and even in ornamentals such as *Ixora* spp. (Giblin-Davis et al., 1992) or annual bedding plants (McSorley and Frederick, 1994). In some instances, cultivars with intermediate levels of resistance can provide a substantial improvement over susceptible cultivars (Gallaher and McSorley, 1993).

Available resistance in plant cultivars can be detected by relatively simple tests, and so there is a good possibility that future sources of resistance will be found. However, there are no assurances that any nematode resistance will be found for some crops. Often, a crop cultivar resistant to one nematode species or race may be susceptible to others. In addition, environmental factors such as temperature may affect the expression of resistance under some conditions (Cook and Evans, 1987).

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CROPPING SYSTEMS

Nematode populations in a site will rise or fall over time, depending on the suitability of the host plants present. Thus, rotations with corn (*Zea mays* L.) or other crops have proved beneficial in managing root-knot nematodes on soybean (*Glycine max* [L.] Merr.) (Kinloch, 1986; Kinloch and Dunavin, 1993). Rotation with pasture grasses can also be advantageous in reducing root-knot nematode densities; Pangola digitgrass (*Digitaria decumbens* Stent.) was effective against *M. incognita* (Kofoid and White) Chitwood (Haroon and Smart, 1983), while bahiagrass (*Paspalum notatum* Flugge) was used against *M. arenaria* (Neal) Chitwood (Dickson and Hewlett, 1989). A disadvantage of rotations with pasture grasses, however, is that fields may be tied up with low-value crops for a long period of time.

Winter or summer cover crops have also been used to manage nematodes in Florida, beginning with early work by Watson (1922) to suppress root-knot nematodes with velvetbean (*Mucuna deeringiana* [Bort.] Merr.). Although it serves as a host to three species of root-knot nematodes, 'Florida 301' wheat has proved effective in lowering nematode population densities in microplots under cool winter conditions (Opperman et al., 1988). Also, 'Wrens Abruzzi' rye (*Secale cereale* L.), a host of *M. incognita*, has proved useful in maintaining (but not increasing) densities of this nematode in the field during the winter (McSorley, 1994). Winter cover crops must be used carefully in nematode management, since some crops and cultivars supporting relatively low nematode reproduction during the winter can support much higher populations when temperatures increase (McSorley et al., 1995).

Some cover crops are effective even in the summer months, when conditions for nematode growth are optimal. Summer sorghum crops reduced densities of *M. incognita* (McSorley and Gallaher, 1991) and *Rotylenchulus reniforms* Linford and Oliveira (McSorley et al., 1987). Hairy indigo (*Indigofera hirsuta* L.) and jointvetch (*Aeschynomene americana* L.) were effective for managing *Belonolaimus longicaudatus* Rau (Rhoades, 1980; 1984). In other instances, legumes and other tropical crops have been used as summer cover crops for suppressing root-knot nematodes (McSorley et al., 1994; Reddy et al., 1986; Taylor et al., 1985).

Although crop rotation and cover crops are useful in many situations, they can have some important limitations. Encroachment of weeds into a rotation crop may invalidate beneficial effects (McSorley et al., 1987). Even if weed growth is avoided, beneficial effects of a rotation may last only for a single season, since nematode populations can resurge after one susceptible crop is grown (McSorley et al., 1994). In addition, a rotation crop effective against one nematode pest may build up densities of other nematodes, if these are present. For example, high densities of *B. longicaudatus* built up on a marigold (*Tagetes patula* L.) cultivar used to manage *M. incognita* (Rhoades, 1980). In another example (McSorley et al., 1994), sorghum-sudangrass (*S. bicolor* × *S. sudanense* [Piper] Stapf) decreased densities of *Meloidogyne* spp. in a field test, but increased densities of *Paratrichodorus minor* (Colbran) Siddiqi. Detailed data on nematode population dynamics are essential for planning effective crop rotations and predicting nematode population trends (Kinloch, 1986; McSorley and Gallaher, 1993). Unfortunately, such data are not available in many instances. In addition, the consistency and influence of environmental effects on nematode population dynamics must be better understood and predicted (McSorley and Gallaher, 1993).

ORGANIC AMENDMENTS

Although organic amendments and mulches have been used to reduce nematode numbers (Stirling, 1991; Trivedi and Barker, 1986), it is not always clear whether improved plant growth resulted from fertilizer effects or nematode control. Organic amendments have not been particularly effective for managing nematodes in Florida. No consistent effects on nematode population levels were observed following addition of municipal solid waste to citrus (Tarjan, 1977) or tomato (Mannion et al., 1994), or of yard-waste compost to corn (McSorley and Gallaher, 1995b). There is evidence that mulching improves plant tolerance to nematodes and their damage (McSorley and Gallaher, 1995a; Watson, 1945).

To successfully use organic amendments for management of nematodes and their symptoms, it is necessary to clearly understand whether the material has a detrimental effect on the nematode, a fertilizer effect on the plant, or some combination of both effects. Efficacy of organic amendments depends on the kind of material used, including the C:N ratio and availability of toxic by-products from decomposition (Stirling, 1991). Application methods and rates, species and kinds of biological decomposers present in the soil, environmental conditions, and other factors affect the consistent performance of organic amendments.

BIOLOGICAL CONTROL

Many efforts have been made to control plant-parasitic nematodes with biological agents such as predators and parasites, but with only limited success (Stirling, 1991). In Florida, the bacterial parasite *Pasteuria penetrans* Sayre and Starr became established in microplots, reducing densities of *M. arenaria* and improving yield of peanut (*Arachis hypogaea* L.) (Oostendorp et al., 1991). However, application of a fungal predator (*Arthrobotrys amerospora* Schenck, Kendrick, and Pramer) of nematodes failed to affect nematode numbers in a greenhouse test and several field trials (Rhoades, 1985). There is evidence that mites and other predators can become established in greenhouse cultures (Walter et al., 1993). Although evidence for successful biological control of nematodes is scarce, many different predators and parasites of nematodes are present in most agricultural soils, where they probably provide some measure of natural control (Stirling, 1991).

TILLAGE

Effects of minimum-tillage practices on nematode densities in Florida crops have not been consistent, except that densities of *Pratylenchus* spp. are usually higher in conventional-tillage plots than in no-tillage plots (McSorley and Gallaher, 1994a). Different methods for managing crop residues in a minimum-tillage system did not have much effect on nematode densities (McSorley and Gallaher, 1994b). Although subsoiling had minimal effects on nematode populations, corn yield was improved due to deeper root penetration (Rich et al., 1986). Since *Pratylenchus* spp. are not usually economic pests in many Florida crops, decisions to use tillage practices should be based on potential agronomic benefits rather than nematode management.

SOIL SOLARIZATION

Soil solarization, or the heating of soil beneath clear plastic, has been used to reduce nematode densities in Florida (Chellemi et al., 1993). In general, it has not been quite as effective as soil fumigation for this purpose (McSorley and Parrado, 1986b; Overman and Jones, 1986). Results depend on length of time the cover is in place, type and thickness of cover, temperature achieved, soil moisture, and seasonal effects including rainfall and cloud cover.

OTHER CULTURAL PRACTICES

Clean fallow is beneficial for reducing nematode densities and weeds (McSorley et al., 1987; Overman et al., 1971; Reddy et al., 1986; Rhoades, 1984; Watson, 1922), but can have undesirable effects on soil organic matter, soil structure, nutrients, and erosion control (Watson, 1922). Flooding can also reduce nematode levels, but may be impractical (Rhoades, 1964). Removal of crop residues and weeds which serve as nematode hosts can be beneficial in many systems (Inserra et al., 1989; Kaplan and MacGowan, 1982; McSorley et al., 1987; Rhoades, 1984), and other practices have been useful in certain situations. These include hot water treatment of citrus (Christie, 1959; Kaplan, 1982), caladium (*Caladium* spp.) (Rhoades, 1970), and banana (*Musa* spp.) (McSorley and Parrado, 1986a) planting material; trenching and root pruning to limit spread of nematodes in citrus groves (Duncan et al., 1990); and minimizing nematode damage by using transplants rather than seeds (McSorley and Gallaher, 1995a) or planting during the winter when nematodes are less active (Watson, 1921).

OUTLOOK

Many different practices have been beneficial for managing nematodes on crops in Florida. A number of these methods may have less environmental impact and may be less expensive than fumigation with methyl bromide, although calculation of the economics of cropping systems is complex and should be made across several crops and seasons. A common concern is that many of these methods may be less effective than fumigation with methyl bromide (Noling and Becker, 1994) although, if the methyl bromide option is lost, many of these methods may be adopted out of necessity. Integration of several management practices may be necessary to maximize nematode management and spread risks (Noling and Becker, 1994; Roberts, 1993).

One important advantage of methyl-bromide fumigation is that the technology is very transportable; its performance is relatively consistent across a range of conditions (Noling and Becker, 1994). Although the principles behind many of the alternative methods are well-known, their effective usage can require detailed, specific knowledge of nematode biology and population dynamics on specific crops and cultivars; accurate estimates of nematode population densities, crop damage and economic thresholds; data on environmental effects; and numerous other factors. Methodology for obtaining such information is available but the task is large, requiring many experiments. In addition, data developed for one region or crop may not be transportable to another region or crop. Therefore, it will be necessary to obtain data and conduct experiments for specific situations. As a result, the use of alternative methods for nematode management could progress unevenly, as those regions and commodities obtaining the necessary research base become more successful in managing nematode problems.

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Nitrogen BMP Program Implementation

K. A. Kuhl*, R. J. Budell, and B. L. McNeal

ABSTRACT

In response to recurring high levels of nitrate-N in groundwaters from selected regions of the state, the 1994 Florida Legislature enacted a Nitrate Bill program. The program decreed that a 50¢ per ton supplemental fee was to be established on all N-containing fertilizers sold in-state, plus increased fees for fertilizer distribution licenses and product registration, and excluding for the present any "natural" materials which are sold without a "tag" or guaranteed analysis. These revenues are to be used in support of BMP research by faculty at the Univ. of Florida/IFAS and at Florida A & M Univ., and for wellwater remediation and cleanup costs with respect to nitrate-N. Enrolled growers who follow the prescribed BMPs or horticulturally-based interim measures (in the absence of demonstrated groundwater-quality effects) are granted immunity from recovery of nitrate-N wellwater cleanup or remediation costs, or groundwater monitoring requirements. To date, a BMP for leatherleaf fern grown in shadehouse environments, and an interim measure for citrus production, have been adopted. The information-gathering, deliberation/negotiation, and rule-making processes accompanying adoption of this BMP and interim measure are described, along with the procedures for solicitation and evaluation of BMP research proposals and the commodity BMP research funded during the first two years of the program. Though the program has been quite time-intensive during its inception, it offers considerable promise as a voluntary grower-enrollment approach to improved fertilizer and irrigation management.

Groundwater and surface water quality with respect to pesticides and nutrients has been a major concern over the past several decades. Though nitrogen (N) enrichment can have important implications even at low levels (< 1 mg L^{-1}) when considering the eutrophication of N-limited lakes and streams, nitrate-N is of particular concern as a drinking water contaminant because of its implication in methemoglobinemia ("blue baby" syndrome) for infants during the first 3-6 months of their lives. There are also antecdotal reports of linkages to decreased learning abilities in some groups of older children, and of possible carcinogenic effects as well. The USEPA maximum contaminant level (MCL) for nitrate-N has been established at 10 mg L^{-1} (10 ppm), and the Florida Dep. of Environmental Protection (FDEP) has been assigned responsibility for assuring groundwater compliance for this and other potential drinking water contaminants throughout the state. Due to the combination of poorly retentive sands, frequent high-intensity rainfall, and relatively shallow groundwater levels, Florida is particularly vulnerable to groundwater contamination problems from nitrate-N and several of the more highly mobile (less retentive) pesticides.

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BACKGROUND

Several geomorphic and/or crop-production settings evidencing major groundwater nitrate problems have been identified to date in Florida. One such area, in northeast Florida, tends to be associated with the commercial production of ferns including leatherleaf fern grown in shade houses. Incidents of groundwater nitrate and pesticide contamination had already been documented for this area during the 1980's, with resultant environmental regulation and multi-party litigation. Beginning in the late 1980's, R. H. Stamps (1996) had initiated studies of fertilization rate and associated irrigation management for leatherleaf fern in the vicinity of the Univ. of Florida/IFAS Central Florida Res. & Education Center (REC) in Apopka, with combined funding from FDEP and the St. Johns River Water Management District. This effort targeted, as a "deliverable" product, a best management practice (BMP) manual for leatherleaf fern grown in shadehouse environments (Stamps, 1995; 1996).

A second major area of demonstrated groundwater contamination from nitrate is throughout the deep, nonretentive sands of Florida's traditional citrus production area along the Central Florida Ridge. During targeted sampling of domestic wells during the late 1980's and early 1990's, ≈ 17% of the domestic wellwaters state-wide proved to be contaminated with nitrates in excess of the USEPA/FDEP maximum contaminant level (McNeal et al., 1995). Of these contaminated wells, 85% were located within a 3-county (Polk, Highlands and Hardee) area along the Central Ridge, and most of the remainder were in adjacent counties where some deep-sand citrus production had historically occurred as well.

FLORIDA'S NITRATE BILL

During the 1994 session of the Florida Legislature, a Nitrate Bill program (Florida Statutes Section 576.045) was established. It was the intent of the Legislature through this modification to the Florida Fertilizer Law (Florida Statutes Chapter 576) to improve fertilizer-management practices (and associated nutrient and irrigation efficiency) as rapidly as practicable, in a way that protects the state's water resources while preserving a viable agricultural industry. This goal was to be accomplished through research concerning BMPs in conjunction with appropriate educational programs and incentives for the agricultural industry and other major users of fertilizer. The program established a 50¢ per ton supplemental fee on all N-containing fertilizers sold in the state, plus increased fees for fertilizer distribution licenses and product registrations, and excluding for the present any "natural" materials which are sold without a corresponding "tag" or guaranteed analysis. To enroll in the program, a grower would need to agree to follow prescribed BMPs for the crop in question (or horticulturally-based "interim measures", having as-yet undemonstrated groundwater quality consequences), with respect to fertilizer application (method, rate, timing as related to source and rainfall/irrigation patterns, etc.) and irrigation amount and/or method. For purposes of this program, BMPs were defined as practices or combinations of practices determined by research or field testing at representative sites to be the most effective and practicable methods of fertilization designed to meet nitrate groundwater quality standards, including economic and technological feasibility. A major incentive for enrolling in the program was provided by granting to enrolled growers immunity from recovery of subsequent nitrate-related well cleanup costs (redrilling or deepening the well, installation of an appropriate water-treatment device such as a reverse-osmosis unit, etc.). Previously, and for non-enrolled growers, FDEP is charged by the Florida Statutes [Section 376.307(3)(c)] with 1) correcting the water quality problem; 2) attempting to locate the source of contamination; and 3) according to Florida Statutes Section 376.307(5), recovering well cleanup and contaminant-tracking costs from the responsible party or parties to the extent possible. During remediation, FDEP must restore or replace contaminated private drinking water wells to a level which meets applicable water quality standards. Such costs can amount to several hundred to a few thousand dollars per single-residence well, and to several hundreds of thousands or even a few millions of dollars for impacted subdivisions. Hence, the risk to growers is substantial in areas evidencing groundwater nitrate problems, and the incentive is correspondingly large.

BMP RESEARCH

Funds generated from the program are targeted both for well cleanup and remediation with respect to nitrate-N contamination (such costs currently exceeding $1 million annually statewide) and for BMP research/demonstration efforts by Univ. of Florida/IFAS and Florida A&M Univ. faculty. Approximately ⅔ of the funds generated ($0.9 million annually during the first two years of fee collection) have been targeted for BMP research during the first years of the project, with the remainder being targeted for well cleanup and remediation. In the latter stages of the program, the respective proportions will be reversed.

In the fall of 1994, a cooperative agreement (Memorandum of Understanding) between the Florida Dep. of Agriculture and Consumer Services (FDACS) and FDEP was established, formalizing respective agency responsibilities and the above-stated funding priorities over the 10-year initial life of the program. Priorities for addressing state-wide nitrate contamination problems were also established at this time, with the resultant order being:

1. Areas of known groundwater nitrate contamination;
2. Other "vulnerable" areas of the state (primarily areas of deep, non-retentive sands having low clay and organic matter contents), as were to be delineated by FDEP during the formative stages of the program; and
3. Additional crops or geographical areas for which BMP development is requested by industry.

INITIAL BMPs

The leatherleaf fern studies by R. H. Stamps (1996) had included an extensive groundwater-quality monitoring component. Hence, it was decided to adopt the resultant BMP manual (Stamps, 1995), along with an appropriate set of record-keeping guidelines reflecting each grower's fertilization and irrigation management practice (Stamps, 1996), as the initial fern-industry BMP for purposes of Nitrate Bill implementation.

No similar document existed for the Florida citrus industry. Fertilization of this crop had long been guided by Univ. of Florida/IFAS Bulletin 536, "Recommended fertilizers and nutritional sprays for citrus", which had evolved over several decades and been most recently updated in 1984. When representatives of the Univ. of Florida/IFAS citrus research and extension community were approached concerning use of Bulletin 536-D (the most recent version) as the basis for an "interim measure" for citrus, however, it was discovered that a revised citrus-nutrition manual was in production, and would be available by April or May of 1995. With the assistance of Univ. of Florida/IFAS researchers and extension specialists, a 1-page draft copy of an interim measure for citrus was evolved from that document in early January of 1995.

In late January of 1995, a series of growers meetings (5 in the Ridge and adjacent Flatwoods citrus-production areas, and 3 in the northeast Florida fern-production region) were held to inform growers of the Nitrate Bill, to explain initial plans for BMP (or interim measure) guidelines, and to receive growers' inputs to the program. The BMP for leatherleaf fern was well-received, because of the much-publicized work which had already been underway for several years by Dr. Stamps at the Central Florida REC (Stamps, 1995; 1996). Sailing was less-smooth for the citrus interim measure, however. Unfortunately, IFAS researchers and extension specialists were concurrently making some major changes in the manner via which N recommendations were made for citrus (returning from the long-term standard of 0.4 lbs (0.18 kg) of N per box of oranges and 0.3 lbs (0.14 kg) of N per box of grapefruit to recommended per-acre or per-ha amounts for each crop instead). New guidelines also more tightly prescribed the number (and associated N rate) of N applications annually and especially near the start of the summer rainy season (with early summer application in particular being targeted for cutback because of the uncertain timing and intensity of the summer rainy season each year). Substantial changes had also been made in young-tree N-fertilization recommendations, but these evoked less grower concern. There was also concern about initial coupling of the interim measure to tissue sampling and analysis in the event that somewhat higher rates of N fertilization were felt to be necessary for a given block or grove;

about assumptions concerning foliar-applied and natural organic sources of N, since N-mineralization and nitrification studies had not generally been conducted for such materials under Florida conditions; and from growers and ag-industry representatives in the traditional fresh-fruit citrus production area along central Florida's Atlantic coast, where no incidents of groundwater contamination with nitrate had previously been reported.

As a result of concerns raised following these initial informational meetings, a special meeting was held with selected representatives of the Florida citrus industry during late April of 1995, under the sponsorship of Florida Citrus Mutual Inc., at which Univ. of Florida/IFAS researchers and extension specialists presented data in support of the newly published recommendations. At an afternoon session later that day, a somewhat-modified interim measure for citrus was voted upon by those industry representatives who were present. The general "flavor" of this draft document was that of a practicable intermediate step between what was perceived to have been long-term citrus production practice, and the recently published Univ. of Florida/IFAS recommendations. Until research-based BMPs could be substituted, the interim measure (hopefully) would be moving groundwater quality towards more acceptable nitrate-N levels.

RULE-MAKING AND EVENTUAL ADOPTION

The BMP for leatherleaf fern (with accompanying record-keeping protocol; Stamps, 1996) and the interim measure for citrus (with accompanying record-keeping protocol as well; Tables 1 and 2) were then taken back to the respective fern and citrus industries in September of 1995 at official, multi-location, "rule-making" hearings. It is the purpose of such sessions to provide a forum for any additional inputs which may be desired from the industry or concerned citizenry, and to allow the opportunity for subsequent "challenge" to the rule if any group does not feel that its concerns are adequately addressed in the proposed rules (Subsequent to the September meetings, one such "challenge" arose, with respect to the recommended N fertilization rate for grapefruit grown under Central Ridge conditions. Upon resolution of this challenge during the summer of 1996, the rule was set in-place and grower enrollment in the program for the two crops was begun). Florida's DEP was no longer authorized to institute proceedings against any person under the provision of Florida Statutes Section 376.307(5) to recover any costs or damages associated with nitrate contamination of water where the nitrate contamination of groundwater is determined to be the result of the application of fertilizers or other soil-applied nutritional materials containing N, provided the property owner or leaseholder 1) provides the Department with a notice of intent to implement applicable best management practices or interim measures adopted by the Department, and then subsequently implements such practices or interim measures according to rules adopted by the Department; or 2) no longer applies fertilizers or other soil-applied nutritional materials containing N. If the property

Table 1. Nitrogen interim measure for Florida citrus.

Maximum nitrogen (N) rates per calendar year are provided in the following table. Available nitrogen from all sources (except foliar-applied formulations) including dry granular, controlled-release, suspension, solution, manure, compost, sludge, and municipal effluent applied to the grove must be included in calculating pounds (or kg) of N per year.

Year in grove	Oranges	Grapefruit	Tangelos	Murcott	Other citrus
	lbs (kg) N tree^{-1} yr^{-1}				
1	.15-.30 (.07-.14)	same	same	same	same
2	.30-.60 (.14-.27)	same	same	same	same
3	.45-.90 (.20-.41)	same	same	same	same
	lbs N acre^{-1} (kg N ha^{-1})yr^{-1}				
4 or more	120-240 (133-266)	120-210 (133-233)	120-250 (133-278)	120-300 (133-233)	120-200 (133-222)

[1]Lower or higher rates may be required during a calendar year due to scheduling, horticultural, or climatic factors, but the average annual rate over a rolling 3 year period may not exceed the maximum rate.

For purposes of this interim measure, the contribution of available N from purely natural organic sources applied during the calendar year shall be 50 percent of the total N content of the source. The total N content of the natural organic product should be determined from either a guaranteed or residual analysis provided by the manufacturer or distributor, or from appendix B.2 in Univ. of Florida Special Publication 169, Nutrition of Florida Citrus Trees (1995).

Application rates, placement and timing. For young non-bearing trees, select a rate in the lower part of the range if there are more than 220 trees per acre (543 ha^{-1}), or if the site is newly converted from pasture or vegetable production. A minimum of 4 applications of dry fertilizer, 10 applications by fertigation, or 1 application by controlled-release formulations is required for non-bearing trees. For bearing trees producing less than 500 boxes per acre (1240 ha^{-1}), rates of N in the low to mid-range are encouraged. A minimum of two applications per year is required for bearing groves receiving up to 150 pounds of N per acre (167 kg N ha^{-1}). Bearing groves receiving more than 150 pounds of N (167 kg N ha^{-1}) require a minimum of three applications per year. Total N applied annually in a block with both bearing and non-bearing trees may not exceed the range for bearing trees. Total N applied annually in a bearing, mixed-variety block may not exceed the range for the predominant variety. Direct fertilizer application to the root zone. The application of at least half of the annual fertilizer N prior to the rainy season is encouraged. Minimize application of soluble N sources during the summer rainy period.

Other considerations. IFAS recommendations for N rates and management are provided in Univ. of Florida IFAS extension publication SP 169, Nutrition of Florida Citrus Trees. This publication describes the benefits of leaf analysis for adjusting fertilizer programs, the advantages of increasing the number of fertilizer applications and reducing the amount applied per application, and the importance of irrigation management in reducing N leaching.

Table 2. Recordkeeping requirements for the nitrogen interim measure for citrus.

Recordkeeping for nitrogen interim measure for citrus.		
A.	Sources of Nitrogen Available N from all sources (except foliar applied formulations) including dry granular, controlled release, suspension, solution, manure, compost, sludge, and municipal effluent applied to the grove must be included in calculation of annual N rate.	
B.	The following information must be easily determined from the landowner's or leaseholder's fertilizer records:	
	1)	The date of application of all fertilizer applications containing N from sources listed above.
	2)	The total N per acre (or per ha) from all sources for each application to oranges, grapefruit, murcotts, Orlando tangelos, or other citrus for each of four age classes: 1, 2 and 3 years, and 4 or more years in the grove. Records should reflect the total N applied per acre (or kg N ha^{-1}) for the predominant variety in a bearing, mixed-variety block.

owner or leaseholder implements best management practices that have been verified by FDEP to be effective at representative sites, there is a presumption of compliance with state nitrate groundwater-quality standards. An added benefit of this assumed compliance with groundwater standards is an exemption from any groundwater monitoring requirements (with respect to nitrates) for enrolled growers as well.

SOME FUNDED RESEARCH ACTIVITIES

Concurrent with the above-described public meetings, a Request for Proposals (RFP) for BMP- related research and demonstration/education activities by Univ. of Florida/IFAS and FAMU researchers and extension specialists was evolved, under the auspices of a BMP Technical Review Committee (consisting primarily of grower, ag-industry, regulatory-agency and university representatives). The BMP Technical Review Committee was charged with prioritizing BMP development, identifying research needs, soliciting research proposals, awarding contracts, monitoring research projects, and rule-making. This committee was in turn responsible to the long-established Fertilizer Technical Council affiliated with FDACS. Concurrently, sampling, sample-handling, and groundwater monitoring protocols were compiled by FDEP and circulated to potential researchers as well. Proposal-submission deadline for the first round of proposed research projects was August 15, 1995, with subsequent review by a 3-person technical panel (from Florida, Texas and California, with a variety of disciplinary expertise), preliminary ranking, oral presentations of surviving projects to the BMP Technical Review group, and final funding decisions (the first grouping of research projects funded by this program, at a total first-year funding level of $438,673, came online in late March of 1996, with the RFP for a second round of funding issued soon thereafter. Initial projects were funded for citrus, young plantings of leatherleaf fern, cotton in the Florida panhandle [in cooperation with researchers at FAMU], and containerized nurseries. Second-year funding subsequently, at a level of $000.00 including new projects as well as second-year funding for the first-year projects, included additional citrus studies, along with studies on golf course greens, greenhouse ornamentals, south Florida vegetables, and tropical fruit).

This program has been quite time-intensive during its inception, in large part due to the number of grower/ag-industry meetings required along with the unfortunate concurrent timing of a major change in the manner by which citrus fertilizer recommendations are made in Florida at the time the program was coming on-line. It offers considerable promise, however, as a voluntary grower-enrollment approach to improved fertilizer and irrigation management, with (hopefully) improved groundwater quality as a result. It appears to be a model that other states may wish to consider as well.

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Developing Improved Irrigation and Nutrient Management Practices: A Case Study—Leatherleaf Fern

R. H. Stamps

ABSTRACT

When developing improved irrigation and nutrient management practices (IMPs), many factors (crop, economic, environmental, nutrient, pesticide, water) must be considered. This review of IMP development for leatherleaf fern is intended to help others who would like to develop IMPs for other crops. IMPs were developed for leatherleaf fern because of high risk of nitrate contamination due to production on highly permeable soils, relatively high nitrogen application rates, and year-round production. Good communication among fern growers, the academic community, and regulatory agencies facilitated IMP development. Both a multi-interest (academic community, cooperative extension service, grower, fertilizer industry, regulatory and service agencies) steering committee and a multi-disciplinary (agricultural engineering, economics, horticulture, and soil science) team of scientists were involved in the research prioritization and initiation process. On-farm surveys, gravimetric lysimeters, field studies with and without surficial aquifer monitoring, estimates of nutrient withdrawals due to crop harvesting, field observations, and research on other foliage crops were each used during IMP development. Maintenance of grower anonymity and protection from prosecution by state agencies enforcing ground water quality standards enabled field trials to be conducted at commercial sites. The commercial acceptance of IMPs will depend upon many factors, and may be partially gauged by the number of growers who sign up to participate in Florida's nitrogen best management practices program.

Improved irrigation and nutrient management practices (IMPs) can benefit agriculture and the environment. However, many factors must be taken into consideration when developing these practices—including crops, nutrients, water, pesticides, environmental pressures, and economics. Crop considerations include crop type, developmental stages, nutrient requirements, nutrient uptake, and management effects on yield and quality. Nutrient management considerations include application site, rates, and frequencies; nutrient sources (soil, fertilizer, and pesticides); and other factors such as the use of adjuvants. Water application method, rate, and amount; scheduling method; and non-irrigation uses of water (chemigation, cold protection) are each important water management considerations. Pesticide management considerations should be integrated with all the other factors as well. Environmental considerations include micrometeorological conditions affecting crop water use, and water resource depletion and contamination. Costs and benefits of current practices and feasibility of modified management strategies also must be considered. Management practices that are not economically feasible, however innovative or intriguing, should not be recommended until such time as they become practical. Because of complex interactions, developing IMPs can be an involved and expensive process. It is hoped that this brief review of the development of improved irrigation and nutrient management practices for leatherleaf fern (*Rumohra adiantiformis* [Forst.] Ching) will help others who would like to do the same for other crops.

DEVELOPING LEATHERLEAF FERN IMPS—BACKGROUND

Leatherleaf fern is the predominant cultivated cut foliage (florists' green) crop produced in the United States, with Florida accounting for over 97% of that production (USDA, 1995). This shallow-rooted herbaceous perennial is grown under shade on highly permeable soils (Fig. 1; Stamps, 1995). The high leaching potential of these soils places ground water at risk of contamination. Typically, solid-set overhead irrigation systems are used to apply 8-0-8 liquid fertilizer at rates exceeding 670 kg nitrogen (N) ha^{-1} yr^{-1} [600 lb N $acre^{-1}$ yr^{-1} (Boggess et al., 1991). Until recently, there had been little incentive for growers in Florida to reduce fertilizer use or conserve water. Fertilizer only accounted for 1.6% of the estimated cost of production (Fig. 2; Smith et al., 1988), and good quality water in large quantities was available from the Floridan aquifer (Ross and Munch, 1980; Rutledge, 1982). However, in the mid-1980s two events occurred that increased concerns about quantitative and qualitative effects of leatherleaf fern production practices on water resources. First, severe advective (windy) freezes in 1983 and 1985 necessitated prolonged pumping of irrigation water onto leatherleaf fern plantings to reduce cold damage (Stamps, 1993). The extended pumping

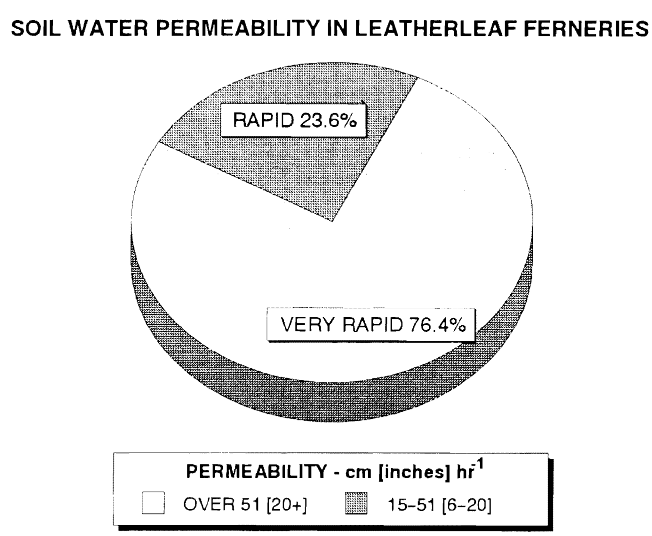

Fig. 1. Water permeability rates of soils typically used for leatherleaf fem production in Florida (Stamps, 1995).

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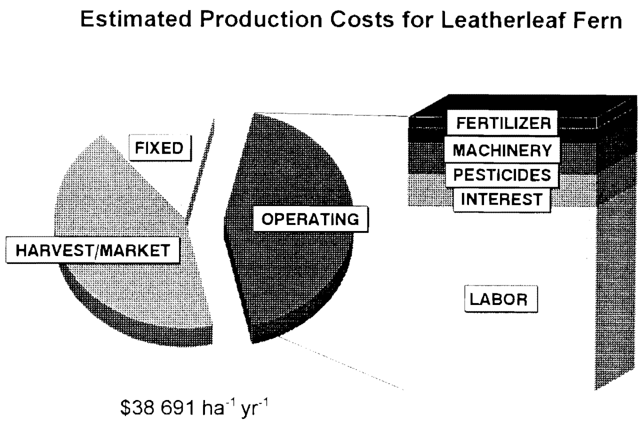

Fig. 2. Estimated production costs for leatherleaf fern (Smith et al., 1988).

temporarily lowered the water table in some areas enough that domestic water wells went dry. Secondly, aldicarb and nitrate nitrogen (NO_3-N) contamination of the surficial aquifer was found to be associated with leatherleaf fern production at one site (Hicks, 1985).

Helpful Preconditions

Several preconditions were helpful in facilitating work on groundwater problems associated with this crop. There had been good working relationships between the Cut Foliage Industry (CFI) and Univ. of Florida (UF) researchers, and between those researchers and pertinent regulatory agencies (Florida Dep. of Environmental Regulation [FDER, now part of the Florida Dep. of Environmental Protection]; St. Johns River Water Management District [SJRWMD]). Research funding for water quantity issues was ongoing between UF and the SJRWMD even prior to the detection of associated water quality problems. There had also been good communications among fern growers, government regulators and the research community, and an established mechanism for continuing the dialogue. That mechanism was a Fern Advisory Committee chaired by a SJRWMD board member. The committee's meetings were open to everyone including concerned citizens, growers, news media, personnel from regulatory agencies, and researchers. All participants had something to gain since the purposes of these meetings were to discuss ways to maximize crop quality, improve economic returns, and conserve and protect water resources. Additionally, the CFI and allied suppliers had built a shadehouse facility for use by researchers where replicated research under near-commercial conditions could be conducted (Stamps and Conover, 1989). Finally, in 1989 the Florida Legislature appropriated $250,000 to FDER to fund work intended to develop best management practices (BMPs) to protect ground water from nitrate contamination.

RESEARCH PRIORITIZATION

Before any new irrigation and nutrient management experiments were started, a set of research priorities were developed using two separate, but overlapping and interrelated, processes. The first process was that of determining general goals and sources of funding. This process consisted of holding multi-interest (academic community [UF], cooperative extension service, grower [CFI], fertilizer industry [Florida Fertilizer and Agrichemicals Association], regulatory agencies [FDER, SJRWMD], service agencies [Florida Dep. of Health and Rehabilitative Services; USDA Soil Conservation Service]) meetings where all parties involved could have input. The second process, starting slightly later and running concurrently with the first, consisted of the development of specific research proposals by a multidisciplinary research team consisting of UF economists, agricultural engineers, horticulturists and soil scientists. Information was freely traded back and forth between the multi-interest group and the research team. This resulted in a prioritized list of research projects, sources of funding for those projects determined to be most important, and a list of potential research sites.

RESEARCH COMPONENTS

Components of the research effort included literature reviews, a grower survey, lysimeter studies, and field studies at new and established ferneries. The grower survey was designed to characterize the leatherleaf fern industry by collecting respondent, fernery, irrigation system, management practice and financial information (Boggess et al., 1991; Stamps et al., 1991). Consistency of data collection was provided by using a detailed pretested survey instrument and having the same individual conduct all the interviews. Studies using gravimetric lysimeters and micrometeorological monitoring equipment, which require a great deal of technical support, were conducted at the Univ. of Florida's Central Florida Research and Education Center in an established fernery. These studies measured crop water use (including adjustment for varying rainfall-seepage patterns at different locations beneath the shade fabric) and effects of fertilization and irrigation scheduling setpoints on nitrogen (ammoniacal, NO_x, and total Kjeldahl) leaching. Field studies were conducted at two commercial ferneries - one that was just being started and one that was fully established. Nitrogen concentrations at the top of the surficial aquifer were monitored at these sites. In addition, replicated experiments with liquid and controlled-release fertilizers were carried out at the shadehouse research facility. At that site, nitrogen concentrations in the root and vadose zones, as well as in the surficial aquifer, were monitored. In all these projects, efforts were made to point out that the data collection efforts were for research purposes, not regulatory ones. Grower/company names were not recorded on the surveys, allowing participants to remain anonymous. Waiver of liability agreements were made between property owners and Florida's Dep. of Environmental Protection prior to taking any samples.

IMPLEMENTATION

Improved nutrient and irrigation management recommendations for leatherleaf fern were developed

Table 1. Summary of the Production Steps and Associated Reporting Requirements for Leatherleaf Fern Growers Enrolled in the Nitrogen BMP Program (Stamps, 1995).

1. **Measure or estimate irrigation system water application rate** (using a flow meter; water collection containers; or established irrigation-rate equations including sprinkler spacing and pattern, sprinkler nozzle orifice size, and water pressure at the nozzle).
2. **Determine soil available water-holding capacity** (based on published information for the various soil series of an area, or on site-specific information obtained by private analytical laboratories).
3. **Schedule irrigations using soil moisture measurements** (e.g., via tensiometers) **or by keeping a soil water budget.** *Do not irrigate on a calendar-based schedule.*
4. **Apply only enough water to replenish the (available) water deficit in the root zone** (including either cycling of tensiometer readings within prescribed limits; or estimation of evapotranspiration, allowable soil water depletion and a reasonable irrigation-application efficiency).
5. **Integrate fertigation and chemigation with irrigation events** to conserve water, and to minimize irrigation run-time and foliar wetting durations.
6. **Consider soil, water, and pesticide nutrient contents when determining fertilizer programs.**
7. **Apply nutrients according to the guidelines established in Stamps (1995)**, keeping concerns about water resource contamination in mind when selecting sources and rates.
8. **Base nutrient application intervals on nutrient release rates** from the various fertilizer sources (also listed in Stamps, 1995).

from the results of the above research projects, from estimates of nutrient withdrawals due to crop harvesting at varying production levels, from additional controlled leatherleaf fern fertilization experiments without aquifer monitoring components, from field observations, and from research on other foliage crops (Stamps, 1995). These guidelines included such basics as measuring irrigation system water application rates, determining soil available water-holding capacities, scheduling irrigations using soil moisture measurement devices (primarily tensiometers) or water budgets, applying only enough water to replenish the available water deficit in the root zone, and integrating fertigation and chemigation with irrigation events. Consideration of nutrient release rates from various fertilizer sources and nutrient contributions from soil, water, and pesticides was suggested. In addition, annual nutrient application rate guidelines, with recommendations to adjust rates depending on the developmental stage of the leatherleaf fern plantings, were established. A summary of steps established for those enrolled in the nitrogen best management practices program is provided in Table 1.

As with any change, adoption of leatherleaf fern IMPs will depend on eliminating impediments and providing incentives. Impediments include perceived or real economic and production (yield and product quality) concerns, distrust of academia and/or government, aversion to added record-keeping, and lack of adequate knowledge about the IMPs. Incentives to adopt the IMPs include altruism/stewardship considerations, potential cost savings, and legislated immunity from litigation (Florida's Nitrogen Best Management Practices [BMP] bill). The percentage of leatherleaf fern producers who volunteer to participate in and honestly commit to the guidelines of Florida's nitrogen BMP program will be a good indicator of whether or not such IMPs can be implemented in this manner in Florida.

The development and implementation of IMPs have the potential to conserve resources, protect the environment, give agriculture an opportunity to improve its image, help growers reduce production costs while maintaining or improving crop quality, prevent the need for costly pollution cleanup, free up regulatory agency resources and personnel to work on other problems, and reduce the need to use limited taxpayer dollars for expensive litigation and cleanup costs. IMPs have the potential to benefit individuals living near agricultural operations, individual companies producing agricultural products, the public at large, and Florida's environment.

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How Do Growers Deal With Regulatory Induced Change?

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ABSTRACT

Florida fruit and vegetable growers continue to face a myriad of regulatory challenges. These challenges result in constant changes for growers. This paper discusses how growers deal with regulatory induced changes, including examples of 1) the adoption of silviculture BMPs for surface-water protection during forest-related operations, 2) the development of BMPs dealing with water disposal from tomato packinghouse dump tanks, and 3) the application of Hazardous Analysis and Critical Control Points (HACCP) techniques to minimize microbiological contamination of food products. Florida-based scientists (i.e., academia) are encouraged to avoid the adoption of far-reaching conclusions based solely on basic research and/or preliminary results, and to become more heavily involved in the extension or implementation of research findings to the point of grower-ready techniques.

In general, there is a full spectrum of ways by which growers deal with regulatory induced changes. Most fall into the following three categories:

—A small portion are proactive and make changes before regulatory action.

—A small group do nothing, ignoring regulations unless forced to comply.

—The largest group waits for regulatory changes to become mandatory, and then react by taking advantage of "cookie cutter" approaches from compliance manuals.

It is important to recognize *why* growers make changes. Most of the reasons fall into two broad categories: 1) what saves or makes money for the grower; or 2) what is required by new regulations. Almost all regulations negatively effect growers' bottom lines one way or another.

Most of the following information deals with examples of how the largest group of growers (as described above) deals with regulatory changes. Two examples of past regulatory issues, and one example of an issue-driven change that the Florida Fruit & Vegetable Association (FFVA) is currently dealing with, will be presented. Also, personal opinions regarding how academia can best help growers deal with these regulatory induced changes will be presented.

The First Example—Silviculture Best Management Practices (BMPs)

Activities associated with silviculture have come under increasing public scrutiny in recent years. Regulatory agencies and environmental groups are concerned about the environmental impacts of forestry activities on wildlife, endangered and threatened species, soil erosion, surface water quality and even ground water quality. Also, logging activities may affect stream sediment and nutrient loads, and water temperature, which in turn affects aquatic ecosystems.

Partially in response to the Federal Clean Water Act of 1972 and anticipating special-interest concerns, the Florida Dep. of Agriculture and Consumer Services (FDACS) called together representatives from a diverse group of interests to find a solution to forestry's perceived problem. These groups included: FDACS, Florida's Dep. of Environmental Regulation (FDER), several water management districts (WMDs), the USDA Forest Service, Florida's Dep. of Natural Resources (FDNR), the Florida Game and Freshwater Fish Commission, private industry, the Florida Forestry Association, Natural Resource Planning Services, Florida Defenders of the Environment, The Sierra Club, The Nature Conservancy, and The Audubon Society. These groups were called together to develop guidelines for silviculture practices designed to reduce the potential impact of forest-related activities on surface water bodies such as streams, lakes, ponds, wetlands, and sinkholes. This group of diverse interests met and agreed upon a common goal: to strike a balance between overall natural resource protection and forest-resource use. Important to the forest industry was that it continue to be economically viable and that the BMPs reflect realistic goals and/or practices. Also important to foresters was the possibility of reducing regulatory duplication by such agencies as the WMDs, FDER, and FDACS. Important to environmental groups was that forestry activities have minimal impact on surface water quality and long-term forest ecosystems.

The group spent many hours in meetings and numerous field trips to better understand forestry activities from a variety of differing viewpoints. The result of their work was the development of a manual for forestry activities entitled "Silviculture Best Management Practices". Basically, this booklet outlines the types of activities which are deemed to be both economically practical and ecologically sound. The BMPs cover the majority of silviculture activities, from land preparation, planting, and maintenance (including prescribed burning and pesticide application), to eventual logging and reforestation operations.

What the forestry industry and environmental groups have achieved as a result of this process is a better understanding of what activities are appropriate, and not appropriate, from both an economic and an environmental/ecological viewpoint. Forestry companies now have basically one-stop permitting and primarily must deal with only one regulatory agency, FDACS. They also have the comfort of knowing that environmental groups have reviewed their procedures and, in general, support their actions. Environmental groups not only have a better understanding of forestry activi-

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ties, but also can feel more confident that these activities are having minimal and carefully considered impact on native ecosystems. With these BMPs in place, environmental groups can also move on to other issues. There is a monitoring requirement which allows for checks and balances to ensure that the programs, as developed, are meeting their intended goals.

A Second Example—Wastewater from Tomato Packinghouse Dump Tanks

Tomato packinghouses use water to move tomatoes throughout the packinghouse and to clean the product prior to shipment. Approximately 6 years ago, a local FDER office observed that this wastewater was indirectly being discharged to surface water. Knowing that industrial wastewater must be permitted, the local inspector immediately initiated enforcement action on the packinghouse. Little did the inspector realize that there were also 30 other tomato packinghouses throughout the state, engaged in similar practices. Soon, FDEP headquarters in Tallahassee became involved in the problem, as well as FFVA and the Florida Tomato Committee.

The three groups undertook several studies to determine: 1) the quality of the packinghouse wastewater; and 2) appropriate disposal activities. At the time (1987/88), each individual packinghouse could do its own testing and apply for its own permitting, or the industry could work as a group to identify and solve potential problems.

To make a long story short, in less than two years the industry had identified three viable solutions which could be utilized by Florida's tomato packinghouses. These were: 1) issuance of a general permit for sprayfield application of the wastewater; 2) discharges directly into sewer systems; or 3) application of the wastewater back onto nearby tomato fields.

These studies and negotiations with regulatory agencies collectively cost the tomato industry approximately $250,000. While this may seem like a large expense, it may have cost each individual packinghouse as much as $100,000 to achieve and maintain compliance had the industry not worked on this project cooperatively. Down-time costs could have been far greater if the problem had been simply treated as a site-specific one for that initial packinghouse.

An Example of Industry Driven Change—HACCP

HACCP is the acronym for Hazardous Analysis and Critical Control Points. The concept of HACCP has been with us for many years, but its application to the fresh fruit and vegetable industry is relatively new. The reason we are concerned about HACCP is the continuing potential for microbiological contamination of food products. Examples of microbiological food contamination include the well-publicized *E. coli* contamination of hamburgers at Jack-in-the-Box restaurants in the Pacific Northwest and, even more recently, the presence of *Salmonella* in some samples of fresh-squeezed orange juice. HACCP is viewed as an effective approach for reducing microbiological contamination and other potential food contamination problems.

Regulators, primarily the Food and Drug Administration (FDA) and, to a lesser extent, FDACS, would like to begin regulating food production over the range from "seed to table", to ensure no microbiological contamination for consumers. This is true even though the vast majority of health problems associated with food products are related to consumer preparation and/or storage.

HACCP was first utilized on a sizeable scale by NASA, for the Apollo missions. HACCP first identifies potential hazards and then develops appropriate Critical Control Points (CCP) to reduce, eliminate and/or monitor potential microbiological hazards.

FDA has now proposed HACCP guidelines for the seafood industry. There also has been a notice of advanced rule-making for all segments of the food industry—from retail grocery stores and restaurants to distributors and packinghouses, and from processing facilities even to the farm level—hence the phrasing "seed to table".

So why is this important to growers? Some of the potential CCPs that have been identified by fresh-cut vegetable processing facilities and by processing companies such as Campbell Soup relate to: the type of fertilizer (i.e. is it synthetic or organic? There is a concern that some organic sources of fertilizers may present a microbiological hazard to consumers); the water source (is it surface water? Is there potential for contamination from processed or even minimally treated sewage? Are there other current or potential users of the surface water source?); the potential for water-source contamination; etc. These are only a few of the many CCPs that have been identified for growers to date.

In this case, the food buyers are currently driving the process and it has become one of almost self-regulation, although FDA and, to a lesser extent, FDACS will probably become involved as well. Hopefully, the produce industry will move toward a technology-based process in this area that provides yet another layer of consumer protection.

If HACCP regulations move to the field, picking of fresh fruits and vegetables will be closely monitored, storage of agronomic and fruit or vegetable products will be monitored as well, and even irrigation and fertilization practices will eventually be monitored. Such monitoring may be conducted by buyers, regulatory agencies, or a combination of both. Whatever the outcome, it is important that comprehensive research and sound science drive solutions in this area, and not simply politics or perception alone.

Academia's Role in Dealing With Regulatory Induced Change

Academia has been involved, and at other times *not* involved, in a variety of environmental issues effecting Florida fruit and vegetable growers. There are some great examples of how *not* to be involved, such as the Everglades issue where "science" based in some cases only upon "best guesses" has already cost growers literally millions of dollars. There are also some great examples of how scientists *can* become effectively involved in regulatory decisions, such as the above-described case of science driving the development of silviculture BMPs. In my opinion, Florida-based or Florida-focussed scientists could improve their involvement in two ways: 1) by never making decisions based solely on basic (often small-plot or laboratory-scale) research and/or on quite-preliminary results; and 2) by subscribing to the viewpoint that extending data to the point of production-level implementation is as important, and often even more important, as the "raw" basic scientific data or the original small-scale studies. In the tomato wastewater example, IFAS accepted a contract from the Florida Tomato Committee and quickly determined that at least five different pesticide residues could be detected in tomato dump tank wastewater. After this discovery, however, the IFAS scientists tended to simply cross their arms and imply that the solution was not really their problem. It appeared to some that IFAS' opinion was that it was sufficient to simply supply the requested data, and then stand aside while regulatory agencies determined whether or not there was an environmental hazard or concern. We have also at times seen a similar approach dealing with food safety, where XYZ microorganism has been detected on ABC fruit. What does that mean! Data like this must be interpreted, explained, and put into proper context if they are to be meaningful in a societal context. Yes, there *are* pesticide residues in tomato packinghouse dump tank wastewater, but only seasonally and at levels 1,000-fold or more below grower use rates. Implementation of basic-research and small-plot data is also extremely important. I submit to you that the task of the scientist is only half completed when a discovery is made. The real work, the real impact, is often in the implementation phase. This is when science truly "takes on a life" and when IFAS scientists make some of their *real* impacts on the citizens of Florida.

SUMMARY

1) Growers make changes for basically two reasons: a) the change makes or saves them money; or b) they are regulated into change. All regulatory changes eventually affect the growers' profit margins or "bottom lines".
2) There are numerous examples of positive ways by which growers have dealt with regulatory change, several of which have been provided in this paper. In one case, a diverse group of special interests decided to leave its natural biases at home and work toward common goals affecting the forestry industry. In another case, an industry collectively developed the data necessary to establish realistic regulations for wastewater disposal, literally saving itself hundreds of thousands of dollars. In still another case, the industry appears to be driving the change itself, in order to avoid public concerns about microbiological contamination of food products. Scientists who tend to work only at the "basic" level, or who tend to leave their findings at the laboratory or small-plot scale, need to seriously consider ways in which their findings can be extended to production scale or real-world settings. Without such activities, the science is generally left incomplete, and in a form where it can too easily be misconstrued by the general public or by those with very specific social agendas. We need to return to the science/industry/ecological partnerships that have worked so well in a variety of settings in the past.

CROPS SECTION

Effects of Root-knot Nematodes on Red Clover Grown in Microplots

N. M. Call, R. A. Dunn, and K. H. Quesenberry*

ABSTRACT

Root-knot nematodes (*Meloidogyne* spp.) damage red clover (*Trifolium pratense* L.) in the southeastern USA. Their effects on yields of the susceptible cv., 'Kenstar', and a resistant breeding line, FLMR6, were evaluated in microplot field studies during the 1993-94 and 1994-95 growing seasons. In 1993-94, plants were evaluated for response to presence or absence of a mixture of *M. arenaria* (Neal) Chitwood, *M. javanica* (Treub) Chitwood, and *M. hapla* Chitwood, and in 1994-95 for response to *M. javanica*. Over both nematode treatments, FLMR6 produced almost twice as much dry matter yield as Kenstar at the first harvest of 1993-94 and during the first three harvests of 1994-95. Dry matter yield of FLMR6 from inoculated and uninoculated plots was not different at any harvest date. During the 1993-94 growing season, inoculated Kenstar plants produced less dry matter yield than uninoculated plants at the third harvest date, and most inoculated plants did not survive the growing season. In 1995, inoculated Kenstar plants produced approximately 50% less dry matter yield than uninoculated plants at the second and third harvest dates and for the seasonal total. Such reduction suggests that root-knot nematode contributed to decreased plant growth. FLMR6 plants flowered earlier than Kenstar plants in both years, due to selection under Florida conditions. There was no effect of nematode treatment on FLMR6 flowering response. Inoculated Kenstar plants were less mature than inoculated FLMR6 plants at the last two harvests of 1994 and at the second and third harvests of 1995. Soil samples from Kenstar plots contained 284 second-stage juveniles per 100 cm^3 soil compared to 2 per 100 cm^3 from FLMR6 plots. The use of the resistant line, FLMR6, should be evaluated as a cover crop for root-knot nematode management in crop rotations.

INTRODUCTION

Among the most important and widespread pests limiting agricultural productivity are the root-knot nematodes. Susceptibility to root-knot nematode limits the production and persistence of red clover in the southeastern USA (Quesenberry et al., 1989). Clover roots infected with root-knot nematode may be heavily galled or stunted, which leads to plant deterioration, secondary fungal infection, and premature death.

Root-knot nematodes decrease plant persistence of several forage species. Root-knot nematodes were a major biotic factor contributing to the lack of persistence of white clover (*Trifolium repens* L.); infected roots were stunted, heavily galled, and deteriorated rapidly, leading to premature plant death (Windham and Pederson, 1991). White clover persistence was reduced by 51 to 79% when infected with *Meloidogyne* species (Baxter and Gibson, 1959), and the number of stolons was reduced from 12 to 20% in plots inoculated with *M. incognita* (Kofoid and White) Chitwood as compared to uninoculated plots (Pederson et al., 1991). Relative to an untreated control, stolon dry weights were reduced by 36 to 83% for plants inoculated with 600 and 1200 eggs, respectively (Brink and Windham, 1990).

Substantial yield losses in alfalfa (*Medicago sativa* L.) have also been attributed to root-knot nematode. The northern root-knot nematode, *M. hapla*, causes stand losses in eastern Canada and the midwestern USA. Yields and persistence of alfalfa were decreased through the failure of seedling establishment, lowered crop production, shortened stand life, and higher disease incidence (Sullivan et al., 1980).

In a greenhouse experiment involving red clover plants inoculated with *M. incognita* or *M. hapla*, all plants inoculated with *M. incognita* died 100 to 150 days after inoculation, whereas a few of the *M. hapla*-infected plants lived longer (Chapman, 1960). Plant symptoms were produced more rapidly by *M. incognita* than by *M. hapla*. Although widely reported to have a negative effect on red clover yields, the magnitude of yield reduction attributable to root-knot nematode infection has rarely been quantified. The objective of this experiment was to quantify the impact of nematode infestation on dry matter yield of two red clovers: FLMR6, which has been shown in greenhouse tests to be resistant to *M. arenaria*, *M. hapla*, *M. incognita*, and *M. javanica*; and Kenstar, which is susceptible to these root-knot nematode species.

MATERIALS AND METHODS

Field studies were initiated in September 1993 and 1994 at Gainesville, FL. The red clover cv. Kenstar and the breeding line FLMR6 were compared in a randomized complete block design with eight replications. FLMR6 was developed by six generations of recurrent phenotypic selection for reduced gall and egg mass score when inoculated with *M. arenaria*, *M. incognita*, or *M. javanica* using 'Cherokee' as the base population. In both years, the main plots were the two red clover entries. In 1993-94, the subplots were the presence or absence of a mixture of *M. arenaria*, *M. javanica*, and *M. hapla*. In 1994-95, the subplots were the presence or absence of *M. javanica*. For both experiments, nematode inoculum was increased on 'Rutgers' tomato (*Lycopersicon esculentum* Mill.) and prepared according to the method of Hussey

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and Barker (1973). Control plots of 'Rutgers' tomato were added to each block during the 1994-95 growing season to monitor soil root-knot nematode activity.

Clover seeds were germinated on moistened filter paper at ca. 25°C. During 1993-94, seedlings were transplanted into styrofoam trays filled with 50 cm^3 methyl-bromide-fumigated Arredondo fine sand topsoil (loamy, siliceous, hyperthermic Grossarenic Paleudults) in each cell, and placed in a greenhouse. After 2 wk of growth, each plant to be planted in the plus nematode subplots was inoculated with a 1500-egg mixture of equal amounts of *M. arenaria*, *M. javanica*, and *M. hapla* by injecting two aliquots of 2 mL each into the root zone of each cell. Two weeks after inoculation, two plants of the plus and minus nematode treatments of each clover were transplanted into microplots constructed of 20-cm-diameter PVC pipe. The PVC pipe was buried approximately 50 cm into the soil with 3 to 5 cm extending above the soil line. The microplots were arranged in rows and columns, 60 and 46 cm apart, respectively. Prior to transplanting, soil assays of microplots indicated that the soil was nematode-free. The plants were inoculated with red clover rhizobium, fertilized, and irrigated as needed for good establishment. During 1993-94 plots only received irrigation when visible wilting was observed, but during 1994-95 they were irrigated for optimal plant growth. The clover plants were manually harvested 4 Mar., 4 Apr., 23 May, and 30 June of 1994. Dry matter yields and flowering stages were recorded at each date. Flowering stage was rated on a 1 to 9 scale: (1) rosette stage, no elongation; (3) rosette, with stems beginning to elongate; (5) buds visible, but lacking color; (7) flower heads open; (9) 50% of heads on plant are brown.

In 1994-95, microplots were first treated with Vapam® (sodium methyldithiocarbamate; ICI Americas Inc., Wilmington, DE) according to label instructions. Microplot soil was then tested for fumigant residue by the lettuce (*Lactuca* spp.) seed test (Dunn, 1993). Two 5-wk-old clover seedlings of the respective clover entries or two tomato plants were transplanted into each microplot. After 4 wk, the plus nematode subplots were inoculated with approximately 2500 *M. javanica* eggs. Eggs were diluted to appropriate concentrations and poured directly into four 5-cm-deep, 3-cm-wide holes bored into the soil profile. The root systems from tomato control plots were removed and examined on 28 Jan. and 31 May to monitor *M. javanica* activity. The clover plants were manually harvested 28 Jan., 11 Mar., 15 Apr., and 31 May 1995. Dry matter yields and flowering stage were recorded on each date as described for the 1993-94 test. In addition, on 31 May 1995, numbers of second-stage juveniles in soil were determined using a centrifugal flotation technique (Barker and Niblack, 1990).

Data were analyzed using CoStat (CoHort Software, 1990). Due to differences in the field layout between the two years, data were analyzed by year and also by harvest date within year. A split-plot model (randomized complete block design) with clover lines as main plots and nematode treatments as subplots was used in both years to analyze the response variables of dry matter yield, flowering stage, total annual dry matter yield, and nematode numbers in soil. If a significant ($P \leq 0.05$) clover line × nematode treatment interaction occurred, data were sorted by clover line and analyzed as a randomized complete block. Since there were only two clover entries and two nematode treatments, an F ratio at $P \leq 0.05$ was used to declare differences.

RESULTS AND DISCUSSION

Analysis of variance showed significant effects of clover lines and nematode treatments, and two-way interactions at some harvest dates for dry matter yield, flowering stage, total seasonal yield, and/or soil nematode level. Thus, the results are presented by year for the response variables, dry matter yield and flowering stage, within each clover entry.

Dry Matter Yield

1994

Yields were highest on the first harvest date, and FLMR6 plots produced greater yields than Kenstar plots (Table 1). However, there were no differences in yield between nematode treatments for either clover line (Table 1). On 4 April, there was no difference in yield between clovers or nematode treatments within clovers. There were no effects of clover lines for yield at any other harvest dates. On 23 May, a clover line by nematode treatment interaction for yield occurred. Kenstar plants inoculated with nematodes yielded less dry matter than Kenstar plants which were nematode-free. No differences were found in yield of nematode-inoculated vs. nematode-free FLMR6 plots. At the 30 June harvest date, absence of effects on yield may be attributed to overall reduced growth of both clover lines at this late harvest date due to hot climatic conditions, disease pressure, and the presence of pests. However, Kenstar plants that were nematode-free survived later into the growing season than inoculated plants.

FLMR6 produced more total dry matter yield than Kenstar for the growing season (Table 1). FLMR6 is more adapted than Kenstar to growth in the lower southeastern USA. An interaction occurred between clover entry and nematode treatment for total yield. Kenstar plots infested with nematodes produced less seasonal total yield than uninfested plots (Table 1), whereas there were no differences in FLMR6 seasonal total yield between nematode treatments. Dry matter yields for both clover populations decreased over the growing season (Table 1). At the second through fourth harvests, yields of Kenstar and FLMR6 plants were similar. Nematode infection decreased the yield and persistence of Kenstar. At the last harvest date, the roots of infected plants appeared heavily galled and stunted. These responses are similar to growth trends for susceptible white clover and alfalfa (Baxter and Gibson, 1959; Sullivan et al., 1980; Windham and Pederson, 1991).

1995

At the first three harvest dates, FLMR6 plants had higher dry matter yield than Kenstar (Table 1). At the

Table 1. Interaction means for dry matter yield of root-knot nematode-inoculated and -uninoculated FLMR6 and Kenstar grown in microplots during 1994 and 1995.

Harvest	FLMR6 Inoculated	FLMR6 Uninoculated	FLMR6 Mean	Kenstar Inoculated	Kenstar Uninoculated	Kenstar Mean
	g plot⁻¹					
1994						
4 Mar.	28 a†	32 a	30 z	9 a	8 a	8 y
4 Apr.	11 a	11 a	11 z	9 a	8 a	8 z
23 May	3 a	6 a	5 z	3 b	10 a	7 z
30 June	1 a	0 a	1 z	0 a	4 a	2 z
Year total	43 a	49 a	47 z	21 b	30 a	25 y
1995						
28 Jan.	23 a	22 a	23 z	8 a	15 a	12 y
11 Mar.	27 a	30 a	28 z	9 b	15 a	12 y
15 Apr.	44 a	51 a	48 z	15 b	35 a	25 y
31 May	13 a	19 a	15 z	14 a	27 a	16 z
Year total	107 a	122 a	114 z	46 b	92 a	65 y

†Means in a row followed by the same letter (a, b within a clover entry; z, y between clover entries) are not significantly different ($P \leq 0.05$).

28 January harvest date, there was no difference between the nematode-inoculated and nematode-free treatments within either clover; however, there was a trend for the inoculated Kenstar plants to yield less than the nematode-free Kenstar plants. Interactions occurred between clover entries and nematode treatments for yield at the 11 March and 15 April harvest dates. On both dates, Kenstar plants inoculated with *M. javanica* yielded less than nematode-free plants. The decline in above-ground biomass production for this susceptible cultivar may be attributed to *M. javanaica* infection. The yields for both nematode levels of the FLMR6 plots were similar at these two harvest dates (Table 1). This suggests that Kenstar was damaged by *M. javanica* infection, while the resistance mechanism in FLMR6 allowed the inoculated plants to produce top growth similar to that for the nematode-free plants. At the 31 May harvest date, there was no difference between FLMR6 and Kenstar yield and no interaction of clovers with nematode treatments.

Over the entire growing season, FLMR6 plants yielded approximately twice as much above-ground dry matter as Kenstar plants. An interaction of clover entries and nematode treatments occurred with regard to total yield. Kenstar plants inoculated with *M. javanica* produced half the yield of uninoculated plants, whereas there was no difference in yield between nematode treatments on FLMR6 (Table 1). Dry matter yields for both clover entries were greatest on the third harvest date, 15 April (Table 1). Yield increased until this date, then declined as daily temperatures increased. Higher yield during the 1994-95 season may have resulted from frequent irrigation throughout the growing season.

Flowering

1994

FLMR6 plants had higher flowering scores than Kenstar plants at the first two harvest dates (Table 2). Approximately 90% of the FLMR6 plants had visible buds or open blooms at the 4 April harvest. FLMR6 plants bloomed earlier in the season than Kenstar, because they had been selected for early growth and vigor under southeastern climatic conditions. On 23 May and 30 June, interactions of clover entries and nematode treatments occurred for flowering stage. The nematode-inoculated Kenstar plants remained in a vegetative growth phase, while the nematode-free plants had entered the reproductive phase (Table 2). This delayed reproductive growth may be attributed to nematode infection. At the 30 June harvest, however, Kenstar plants inoculated with nematodes were dead (Table 1); consequently, no reproductive growth would be expected (Table 2). There was no difference in the flowering stage of nematode-infested FLMR6 plants and nematode-free FLMR6 plants. Apparently, neither the vegetative nor reproductive growth of FLMR6 plants is suppressed when inoculated with polyspecific mixtures of root-knot nematode populations.

1995

At the first three harvest dates, Kenstar plants remained in a vegetative growth phase, whereas FLMR6 plants reached near full reproductive maturity (Table 2). On 11 March and 15 April, a nematode treatment by clover entry interaction occurred. Uninoculated Kenstar plants ranked higher for reproductive stage than the inoculated plants (Table 2). This suggests that nematode damage to Kenstar roots reduced nutrient uptake and overall plant growth.

Nematode Recovery From Soil, 1995

On 31 May, more second-stage juveniles were recovered from nematode-inoculated Kenstar microplots (284 per 100 cm^3 soil) than from nematode-inoculated FLMR6 (2 per 100 cm^3 soil) microplots. The control microplots of tomatoes averaged 835 nematodes per 100

Table 2. Flowering stage of root-knot nematode-inoculated and -uninoculated FLMR6 and Kenstar grown in microplots for two consecutive years.

Harvest	FLMR6			Kenstar		
	Inoculated	Uninoculated	Mean	Inoculated	Uninoculated	Mean
	flowering stage†					
1994						
4 Mar.	6 a‡	6 a	6 z	1 a	1 a	1 y
4 Apr.	9 a	9 a	9 z	4 a	5 a	4 y
23 May	7 a	5 a	6 z	4 b	9 a	6 z
30 June	3 a	2 a	2 z	0 b	4 b	2 z
1995						
28 Jan.	3 a	3 a	3 z	1 a	1 a	1 y
11 Mar.	4 a	4 a	4 z	1 b	2 a	2 y
15 Apr.	8 a	9 a	8 z	3 b	4 a	4 y
31 May	9 a	9 a	8 z	9 a	8 a	8 z

†Flowering stage was rated on a 1 to 9 scale: (1) rosette stage, no elongation; (3) rosette, with stems beginning to elongate; (5) buds visible, but lacking color; (7) flower heads open; (9) 50% of heads on plant are brown.

‡Means in a row followed by the same letter (a, b within a clover entry; z, y between clover entries) are not significantly different ($P \leq 0.05$).

cm³ soil. No nematodes were recovered from most uninoculated plots. Thus, the number of *M. javanica* juveniles in inoculated plots of FLMR6 was not different from the mean number for all non-inoculated plots. No interaction of clover entries and nematode treatments occurred. These results are similar to those reported previously from greenhouse studies in which *M. arenaria* numbers at 120 d after inoculation were 328 for Kenstar vs. 2 per 100 cm³ soil for FLMR6 (Call et al., 1996), and in which *M. javanica* numbers at 120 d after inoculation were 126 for Kenstar vs. 7 per 100 cm³ soil for FLMR6 (Call et al., 1997).

SUMMARY AND CONCLUSIONS

In both years, FLMR6 resulted in twice the dry matter yield of Kenstar, which can partially be attributed to its adaptability to southeastern climatic conditions. Dry matter yields for the 1994-95 growing season were substantially greater than for the 1993-94 growing season, which may be partially attributed to management factors, including increased irrigation. Yields of FLMR6 were higher than for Kenstar at the first harvest of 1994 and the first three harvests of 1995.

The red clover breeding line FLMR6 is tolerant to root-knot nematode infection. No differences occurred at any harvest dates between nematode treatments in FLMR6 plots. Root-knot nematodes apparently affected above-ground biomass production of Kenstar plants. In 1994, inoculated Kenstar plants yielded less than uninoculated plants at the third harvest date and for the seasonal total. The inoculated plants did not survive throughout the growing season. In 1995, inoculated Kenstar plants yielded less than uninoculated plants at the second and third harvest dates and for the seasonal total, suggesting that *M. javanica* decreased production.

FLMR6 plants reached full bloom earlier than Kenstar plants in both years. Population FLMR6 elongated earlier in the season as a result of its adaptation to Florida climatic conditions. There was no difference in reproductive stage of FLMR6 between nematode treatments. However, reproductive growth of nematode-inoculated Kenstar plants was retarded in both years.

Nematode population densities in soil increased to higher levels on susceptible Kenstar than on FLMR6 red clover. Numbers of juveniles recovered from FLMR6 plots were <1% of those recovered from Kenstar plots. When managing root-knot nematode populations, especially in crop rotations, the use of a resistant cover crop may inhibit endemic population numbers. The resistant breeding line FLMR6 should be evaluated as a cover crop for root-knot nematode management in multiple cropping systems.

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Occurrences of and Some Factors Affecting Blue Mold of Tobacco in Florida from 1921 to 1995

T. A. Kucharek*, T. R. Young, and W. D. Thomas

ABSTRACT

Blue mold (BM) of tobacco (*Nicotiana tabacum* L.), caused by *Peronospora tabacina* D. B. Adam, occurred in at least 56 of the past 75 years in Florida, with its first appearance being in 1921 in Gadsden County. Although most occurrences have been in the north central portion of the state, where flue-cured tobacco is grown, and in the Gadsden County area, where shade tobacco was formerly grown, BM has been identified from Walton County in the panhandle to Dade County on the southern tip of the peninsula. Blue mold appeared in plant beds and in the field at least 45 and 35 years of the 75 years, respectively. From 1979 to 1995, when more detailed information about BM was gathered, first appearances in north Florida were in February, March, April, May, or June. These first occurrences were on different farms in seven different counties. Although above-average rainfall has been associated with first occurrences, six occurrences from 1980 to 1993 were associated instead with dry to extremely dry weather. In these instances, growers had used enough irrigation to increase moisture to above-normal levels based on 30-year averages. Further support for the strong influence of irrigation occurred in 1995, when the use of drip irrigation reduced the level of BM by 93% when compared to the use of overhead irrigation. Resistance in the blue mold pathogen to metalaxyl first appeared in Florida in 1991, and was widespread by 1995 during a major epidemic. The occurrence of resistance to metalaxyl in Cuba and other Caribbean countries in 1981 precludes those areas as being consistent sources of inoculum for Florida. The potential for the existence of oospores in Florida is discussed.

Flue-cured tobacco is a major crop in north central Florida and, up through 1977, shade tobacco was a major crop in the Gadsden County area. Tobacco grown south of Marion County has been primarily for transplant production.

Blue mold (BM) of tobacco, caused by *Peronospora tabacina* D. B. Adam, first appeared in the United States in the Gadsden County area and in south Georgia during 1921 in shade tobacco (4). Interestingly, BM did not appear again in Florida until 1931 (12). Blue mold is generally regarded as a disease that spreads rapidly during cool and wet conditions and that causes considerable damage, particularly in transplant beds (7). Damage from BM includes transplants that are weakened or killed, and harvested leaves that have lower grades and lower yields. Beginning on 9 May 1979, a major epidemic of BM began in a field in Alachua County, FL and caused considerable damage throughout the eastern United States (6,10). The initiation of that epidemic and other first occurrences in Florida were related to above-average rainfall across a broad range of temperatures (6).

Florida is commonly thought to he a major source of inoculum for blue mold for the remaining tobacco-growing areas of the United States (9,10). Further, it has been theorized that the source of inoculum for BM in Florida is from sporangia of the fungus being wind-disseminated from Cuba or other countries in the Caribbean (8,10). Main (8) states definitively that "The pathogen does not overwinter in the U.S. and must be introduced each year from the Caribbean and Latin America". Some have unofficially speculated that a permanent reservoir of inoculum exists "somewhere" in Florida. In fact, the actual source of inoculum for Florida has never been found. Although oospores of the fungus exist, their documented presence is uncommon (9,14), and they have never been seen in Florida, even with extensive examination of diseased tissue (Kucharek, unpublished; Spurr and Main, unpublished).

Bonde (3) proposed at a symposium that, of 126 identified problems associated with studying BM, identifying the sources of primary inoculum was among the top 11 priorities. The purpose of this paper is to examine natural epidemics of BM in Florida for clues related to the source(s) of inoculum. Factors that were examined were: times of first occurrences from 1921 through 1995, specific locations of first occurrences from 1979 to 1995, sites of first occurrences (plant bed vs. field), relationships of moisture events to first occurrences from 1979 to 1995, and temporal and spatial occurrences of insensitivity to metalaxyl from 1980 to 1995.

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MATERIALS AND METHODS

Accession of Blue Mold Incidence Data

Occurrences of BM in Florida from 1921 to 1969 were attained from the Florida Agric. Exp Stn. Reports (1) and Burger and Parham (4). Other individuals whose experiment station reports contained information about BM included L. O. Gratz (Hastings), R. R. Kincaid (Quincy), W. B. Tisdale (Quincy and Gainesville), R. K. Vorhees (Gainesville), K. W. Loucks (Leesburg), F. Clark (Gainesville), and S. Brothers (Gainesville). Diagnostic records of occurrences of BM from 1921 to 1995 in transplant production areas were made available from the Bureau of Plant Pathology, Division of Plant Industry by Dr. Tim Schubert. Occurrences of BM from 1970 to 1995 were available from the senior author's surveys. In addition, E. B. Whitty (personal communication) provided supporting information related to tobacco production techniques that interacted with BM.

Because of the sudden epidemic of BM beginning in the field on 9 May 1979 in Alachua County and continuing throughout the tobacco-growing areas of eastern North America, detailed records on occurrences of BM in Florida were kept with respect to location by county, farm, and site (plant bed or field) from 1979 to 1995. Additionally, occurrences of BM in other states were available through a collaborative organization started in 1980 and known as the Blue Mold Warning Service. It was operated by Extension plant pathologists throughout the tobacco-growing regions of the eastern United States and Canada. Information for Florida was acquired by field visits in all cases; emphasis was on the flue-cured tobacco production area of north central Florida.

Accession of Rainfall and Irrigation Data

Rainfall data for the years 1979 to 1995 were attained from Climatological Data (Volumes 83 to 99) published by NOAA (National Climatic Center, Ashville, NC). Synoptic rainfall from the NOAA weather station nearest to a farm site was used confidently because nearly all rainfall events during February, March, April, and May were associated with broad frontal passages rather than erratic convective storms. Irrigation data were acquired from growers to the nearest 1.3 cm. Tobacco growers typically maintain records of their irrigation inputs.

Comparison of Drip vs. Conventional Irrigation

In 1995, a grower in Columbia County compared the use of drip irrigation and plastic mulch with his conventional production practice using no plastic and overhead irrigation. Each system was in a separate field, but on the same farm. The percent BM on the seventh leaf above the soil was assessed for percent of leaf area with BM for 24 consecutive plants in each of six rows (reps). Disease data were transformed and analyzed using a square root of percent plus 1/2, and compared using an unpaired Students' test.

Isolate Sensitivity to Metalaxyl

Sensitivity of isolates of *P. tabacina* from tobacco to metalaxyl (N-[2,6-dimethylphenyl]-N-[methoxy-acctyl]-DL-alanine methyl ester) was tested by applying a known concentration of metalaxyl to 6- to 8-week-old seedlings of the tobacco cultivar 'Coker 319'. Each concentration was applied to six plants for each isolate. Test plants were inoculated either with one of the collected strains or a known sensitive strain using 45 000 to 50 000 spores per mL of distilled water. Approximately 1.0 to 1.5 mL of the spore suspension was ample to atomize a plant having two to three leaves. Plants inoculated with a specific strain were then placed in a crisper to avoid contamination. After inoculation, the plants within the crispers were kept in darkness at 15°C for 24 h. The plants were kept for 5 d at 21-23°C with a 12 h day/night cycle. Finally, the plants were returned to 15°C with darkness for 24 h. When further incubation was needed, plants were again returned to 23°C under the diurnal cycle for an additional 2 to 3 days. Metalaxyl-insensitive strains sporulate on plants treated at a rate of 100 ppm, while sensitive strains produce no sporulation at 10 ppm metalaxyl or more.

RESULTS

General History of Blue Mold in Florida

Blue mold first occurred in Gadsden County Florida in 1921, both in plant beds and in the field. It did not appear again until 1931, and then occurred in Florida each year from 1931 to 1960. It did not appear in 1961, 1969, 1972, 1973, 1974, 1975, 1976, 1985, 1988, 1989, 1990, or 1994. For the 75-year period from 1921 to 1995, BM appeared in 54 years.

Blue mold was not found south of Marion County until 1957, when it occurred at Zolfo Springs in a transplant production system (Table 1). Of the 14 cases of BM in south Florida, 11 occurred between 1957 and 1969 and all were on transplants. The only other known cases of BM on transplants in south Florida were in 1980, when BM was epidemic at many transplant production sites. Two other cases of BM occurred in south Florida during 1978 and 1979, and these were associated with commercial tests.

Occurrences of BM in the flue-cured tobacco area of north central Florida or in shade tobacco areas of Gadsden County did not change appreciably over the 75-yr period except that no BM was found in the shade tobacco area from 1971 to 1977, after which time shade tobacco was no longer grown in Florida (Table 1). The western-most occurrence of BM in the state was in the panhandle in Westville, within Walton County in a transplant production system, in 1957.

Blue mold appeared in plant beds in 45 of the 75 years, with a high rate of incidence from 1946 to 1970 (24 of 25 yr), followed by a drastic reduction in such incidences from 1971 till 1995 (Table 1). This reduction coincided with the intensive use of plastic covers for plant beds in north Florida; the use of metalaxyl, which attained labelling in mid-season in 1980; and the phas-

Table 1. Some general characteristics of occurrences of blue mold in Florida for the 75-year period from 1921-1995.

	Years		
Blue mold occurrences	1921-45	1946-70	1971-95
No. yrs south of Marion County	0	11	3
No. yrs in north central Florida	13	17	14
No. yrs in Gadsden county area	16	20	0
No. yrs in plant bed	14	24	7
No. yrs in field	11	10	14
No. yrs in plant bed and field	11	9	6
No. yrs in plant bed but not field	2	15	1
No. yrs in field but not plant bed	0	1	8
No. yrs severe epidemic occurred	5	5	4
Months of first occurrence in Florida	Feb. Mar. Apr. May	Mar. Apr.	Feb. Mar. Apr. May June

ing out of field-grown transplants in south Florida by the mid 1980's.

Blue mold occurred in the field in 35 of the 75 yr (Table 1). The highest incidence of BM in the field occurred between 1971 and 1995, which coincided with a progressive increase in irrigation of tobacco in the field. Dramatic increases in incidences in the field were not always associated with inoculum coming from the plant beds, as indicated by the fact that eight of the 14 cases in the field from 1971 to 1995 occurred during years when no BM appeared in the plant beds.

All but one of the first occurrences of BM in Florida were in February, March, April, May, or June (Tables 1 and 2). The one exception occurred during December 1979/January 1980 in Dade County, on some tobacco being grown for a seed company (Table 2).

In the north central portion of Florida, epidemics from 1979 to 1995 started during February, March, April, May, or June and originated in seven different counties during the 12 years BM occurred in north Florida (Table 2). In addition, each first occurrence was on a different farm Some first occurrences were in the field and some were in plant beds. For the 16 years from 1979 to 1995, seven first occurrences in the United States were in states other than Florida. In 1992, the first occurrence was in Florida and Kentucky on the same day (May 15).

Occurrences of Blue Mold During Dry Weather

Whereas the initiation of the epidemic in 1979 began after a 30-d period that included 11 rain events and

Table 2. Locations of first occurrences of blue mold (BM) in Florida from 1979 to 1995.

Year	Date	County	Florida Farm	Plant bed or field	First state with BM
1979†	May 9	Alachua	Chastain	Field	FL
1979	Dec-Jan‡	Dade	Graves	Field	
1980†	Feb 29	Suwannee	Moore	PB	FL
1980†	Mar 5	Osceola	Willingham	PB	
1981	Mar 23	Dixie	Bell	PB	FL
1982	Apr 15	Suwannee	ARC§	Field	FL
1983†	Mar 7	Alachua	Hill	PB	FL
1984	May 22	Alachua	Spencer	Field	FL
1985	None				GA
1986	Apr 15	Madison	Webb	PB	FL
1987	Jun 15	Union	?	Field	TN
1988	None				KY
1989	None				KY
1990	None				KY
1991	Mar 29	Columbia	Feagle	PB	FL
1992	May 15	Hamilton	Bennett	Field	FL & KY
1993	Apr 21	Columbia	Kirby	Field	GA
1994	None				KY
1995†	Mar 31	Alachua	Univ. of FL	PB	FL

†Epidemic year.
‡Seed company test; BM appeared in Dec., treated with metalaxyl and non-sporulating lesions present in Jan. 1980.
§Agricultural Research Center, Univ. of Florida.

Table 3. Influence of irrigation (Irr) on appearance of blue mold in tobacco during dry weather.

				Moisture events for the 30 days prior to occurrence			
				Amount (cm)		No. of events	
Case† and site	Date of occurrence	County	30 yr. avg. rain	Rain	Irr.	Rain	Irr.
AF‡	5/09/79	Alachua	8.4	16.0	0.0	11	0
DB	3/22/80	Alachua	9.9	7.9	15.2	10	6
IB	3/23/81	Dixie	9.9	5.8	10.2	6	8
RF	5/22/84	Alachua	9.7	1.3	30.5	4	4
SB	4/05/86	Madison	9.9	5.6	14.5	2	16
TF	5/08/86	Suwannee	10.9	3.6	27.4	1	23
UF	5/26/93	Columbia	11.2	1.3	20.3	1	6

†Case = farm; site: B = plant bed & F = field.
‡For comparison, as this case occurred after rain.

nearly double the amount of normal rainfall for that period of time, six occurrences of BM were identified from 1980 to 1993 that were associated with below average rainfall for the 30-d period prior to occurrence of disease (Table 3). For these six cases, rainfall plus irrigation amounts still exceeded normal rainfall amounts by a factor of 1.6 to 2.8. At one location, 23 irrigation events occurred, and that site had the highest level of overhead moisture. Four rain events and four irrigation events occurred at the site in Alachua County where BM occurred in 1984. An adjacent field of tobacco received only one irrigation in addition to the four rain events, and no blue mold was present.

Comparison of Drip vs. Overhead Irrigation

At 88 days after planting in 1995, both fields managed by this grower had BM, but the level of BM in the field with drip irrigation appeared to be considerably less than in the field with overhead irrigation. The field with drip irrigation received 17.5 cm of overhead water from six rain events, and no overhead irrigation from the time the transplants were set until BM was measured. The conventionally produced field received 18.4 cm of rain from six events plus 21.6 cm of irrigation water from six additional events. For the 30 d prior to assessing BM, the drip field received three rain events for a total of 6.9 cm of water. The conventional field received 7.6 cm of water from three rainfall events plus an additional 3.8 cm of overhead irrigation from one irrigation. Blue mold was reduced by 93% ($P = 0.001$) for an average severity of 0.97% to 0.07% for the conventional field and drip field, respectively.

Isolate Sensitivity to Metalaxyl

The first complaints from growers that metalaxyl was not controlling BM in Florida occurred in 1991, 11 yr after the first use of metalaxyl in North America, South America, Central America, and the Caribbean. Insensitive isolates of *P. tabacina* were first encountered in Nicaragua, the Dominican Republic, and Cuba in 1981, one year after the first use of metalaxyl.

Nine samples were acquired from north Florida during the spring of 1991 and all nine were insensitive to metalaxyl. In 1995, another severe epidemic of BM occurred in Florida. Metalaxyl was used extensively by growers, but BM was not controlled. Thirteen isolates were evaluated and all 13 were insensitive to metalaxyl.

DISCUSSION

Based upon its common occurrences over the past 75 yr, BM can be expected to occur during most years in Florida. Of continual concern to growers and academicians in Florida and other states has been the source of primary inoculum for a given epidemic. It has been speculated commonly that Florida is a major source of inoculum for the tobacco-growing regions further north, and that Cuba is the origin of sporangial inoculum for Florida (5,8,9,10). These scenarios were based upon temporal and spatial wind trajectory analyses and on the common occurrence of Florida as the first eastern state in the United States to have BM.

Florida must be considered as a source of inoculum for other areas of North America as well, because BM was first found in the United States in 1921 in north Florida and south Georgia and the disease gradually spread northward. By 1937 most of the tobacco-growing regions of the southeastern U.S. had BM (12). Interestingly, BM did not appear beyond north Florida or south Georgia in 1921. If long-distance spore dispersal occurs commonly BM should have occurred further north, since the epidemic in 1921 lasted from March through June. A more gradual dispersal of spores to adjacent or nearby areas is not contested. Miller's (12) descriptive maps of incidences of BM from 1921 till 1937 depict a more gradual dispersal throughout the tobacco-growing states. Blue mold did not appear in Kentucky until 1937. In our studies, we were able to use a natural marker, metalaxyl insensitivity, to further cast doubt on the argument that long-range transport of sporangia from Cuba and other countries in the Caribbean is the common source of inoculum for Florida. Metalaxyl-insensitive isolates abounded in the Caribbean beginning in 1981, but such isolates were not detected in Florida until 1991. Certainly, if long-range dispersal of sporangia occurred commonly from the Caribbean, failure of metalaxyl to control BM should have occurred much sooner in Florida.

Florida should not be considered the only source, or even a major source of inoculum, in some years. Blue mold has occurred in other states during years when Florida had none; for example, 1985, 1988, 1989, 1990, and 1994. While BM did not occur in Florida during 1985, it was first found in southwest Georgia in late May. Shortly thereafter, BM appeared in Kentucky and the disease then spread to neighboring states. Interestingly, BM had been in Cuba and the Dominican Republic since January of 1985. However, the final analysis for the 1985 epidemic, and other epidemics in the upper tobacco-growing region of the United States, linked the source of inoculum to Texas where *Nicotiana repanda* Willd., a wild tobacco, commonly is found with sporulation of *P. tabacina* (5). Thus, a conceptual nuance exists because most theories have been conjectural and circumstantial.

By viewing the entire history of BM in Florida in relation to statewide, national, and regional (Caribbean) incidences, the credibility of the concept of long-range dispersal of sporangia as being the sole source of inocula for every epidemic is questionable. The question here is whether multiple sources of inocula exist within states and different regions. The fungus *does* produce oospores, but they are not found commonly nor in some areas at all (7,9,13). However, it would not likely require many oospores to initiate an epidemic. For *Phytophthora* spp., Mitchell and Kannwischer-Mitchell (13) discuss the multiple situations where extremely low levels of inocula (sometimes undetectable), the low viability of propagules, cropping types (e.g. annual vs. perennial), and other factors preclude establishing predictive systems and allowing for a complete elucidation of relationships between levels of soil inocula and levels of disease.

That oospores might be a source of inoculum for BM within Florida is supported by several indicators. First, no other source of inoculum has been found. This includes the failure to link naturally marked populations of *P. tabacina* (metalaxyl-insensitive) between the Caribbean and Florida, and the absence of infected volunteer plants of tobacco. However, searches for source plants should continue. Although some other solanaceous crops (peppers, tomatoes, and eggplants) were observed at one time in North Carolina to be infected with *P. tabacina* (2), this has never been verified elsewhere (11) nor observed in Florida. Secondly, first occurrences of BM from 1979 to 1995 were closely linked to multiple rainfall and irrigation events over a broad time span (February to June) covering many years. Such a pattern is highly suggestive of a source, like an oospore, that possibly would be stimulated to germinate by wetting and drying cycles. Thirdly, the specific locations of first occurrences of BM in Florida from 1979 to 1995 were all in different fields or plant beds in multiple counties where frequent moisture events were documented. If a common source of inoculum on some host plant were to exist, one would expect to find first occurrences of BM to be somewhat site-specific rather than being so widely scattered. The occurrences of BM in heavily irrigated fields during extremely dry weather, such as in 1984, support the contention that the inoculum is already present within the irrigated site. Most, if not all, fields and transplant beds where BM first occurred in Florida from 1979 to 1995 had been used intensively for tobacco production in the past.

In summary, BM is likely to be a continuing problem in Florida. In order to best direct control tactics against this disease, we need to determine definitively what is/are the primary source(s) of inoculum. It is likely that locally produced oospores are the predominant, primary source of inoculum rather than transported sporangia from the Caribbean.

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Grazing Response to Rye Populations Selected for Improved Yield

R. N. Gates*, G. M. Hill, J. W. Johnson, and P. L. Bruckner

ABSTRACT

Rye (*Secale cereale* L.) populations representing the fifth (C5) or seventh (C7) cycle of recurrent phenotypic selection for forage yield from a 'Wrens Abruzzi' (WA) base population were evaluated in two grazing trials. C5 and WA were each planted in two pastures (0.81 ha) during October 1991; four pastures of C7 and WA were planted during October 1994. N fertilization totalled 168 kg ha^{-1}. Grazing began in early December and ended in mid-March. Herbage mass, equalized with put-and-take stocking, was estimated visually in 1991-92 and using biweekly clipped samples in 1994-95. Heifers grazed for 106 d, gaining 0.82 kg d^{-1}, in 1991-92. Rye population did not influence animal production. Herbage mass declined from 1220 kg ha^{-1} in January 1995 to 490 kg ha^{-1} in March 1995. IVDMD of clipped C7 samples (751 g kg^{-1}) was higher ($P < 0.05$) than for WA (738 g kg^{-1}). However, daily gain (1.27 kg) and carrying capacity (439 d ha^{-1}) of steers were not influenced by rye entry. High forage quality of the rye supported rapid animal growth. Apparently energy concentration of the forage was not limiting animal performance with either rye population.

Grasses which grow during the cool season in the lower South are generally of high nutritional quality. However, dependable forage supply during this period is limited by poor persistence of perennial cool-season grasses. Hoveland (1986) suggested that grazing weaned calves during the cool season represented the greatest opportunity to increase profitability of beef production in the Southeast. He noted further that small grains were the traditional forage crop of choice. Hill et al. (1985) and DeRouen et al. (1991) demonstrated that grazing supplemental cool-season annual pastures, including ryegrass and small grains, could reduce hay feeding costs and increase cow and calf weights compared with winter hay feeding. Bruckner and Raymer (1990) documented that rye was more productive in January and February than wheat (*Triticum aestivum* L.), oats (*Avena sativa* L.) or triticale (X *Triticosecale* Wittmack). Mid-winter is generally the period of most limited forage supply, verifying the motivation to select rye for winter grazing. Kouka et al. (1994) suggested, however, that rye was a less profitable forage for winter grazing than oats or a rye-ryegrass mixture, because season-long gains and carrying capacity tended to be lower.

Recurrent phenotypic selection (Burton, 1974; 1982) of rye was initiated in 1985 from a base population of Wrens Abruzzi. Evaluation of germplasm from the fourth cycle of selection indicated a dry matter yield gain of 6-7% per cycle for spaced plants, but only 2-3% per cycle for seeded plots (Bruckner et al., 1991). Selection was continued and cycle 7 was completed in 1992. Seed increases made from cycle 5 and cycle 7 germplasms provided sufficient seed for grazing trials, conducted to compare growth of weaned calves grazing selected rye germplasms with that supported by the base population. Variables included daily gain, carrying capacity, liveweight gain per hectare, and digestibility of forage on offer.

MATERIALS AND METHODS

Experiment 1

Rye entries, either Wrens Abruzzi or cycle 5, were each randomly assigned to two fields (0.81 ha each) containing Tifton loamy sand soil (fine, loamy, siliceous, thermic Plintic Kandiudults). Seedbeds were well-prepared by disking. Seed was drilled (125 kg ha^{-1}) 3 Oct. 1991. Fertilizer (94 kg N ha^{-1}, 10 kg P ha^{-1}, 39 kg K ha^{-1}) was applied in mid-November. Additional nitrogen (74 kg ha^{-1}) was applied in mid-January.

Continuous grazing began 3 December with the assignment of three tester heifers (206 kg) to each pasture. Biweekly herbage mass assessments were made visually by one or two observers. Put-and-take heifers were added or removed biweekly as needed to maintain equivalent declines in herbage mass among pastures. Grazing was discontinued 19 March when herbage mass was judged to be limiting. Initial and final weights were computed as the mean of full weights taken on two consecutive days at the beginning and end of the experiment.

Experiment 2

Procedures followed for the second grazing experiment (planted 1 Oct. 1994) comparing cycle 7 to Wrens Abruzzi were similar, with the following exceptions: each rye entry was randomly assigned to four pastures, grazed with three weaned tester steers (270 kg). Grazing began 8 December and was discontinued 8 March. Put-and-take steers were added and removed to maintain comparable declines in herbage mass. Spring stocking rates were increased to maintain high levels of defoliation and reduce maturation of rye plants. Steers had access to free-choice mineral providing 60 to 200 mg lascalocid per steer daily. All steers were implanted with Synovex-S® on d 1 of the trial. Herbage mass was estimated biweekly by cutting a 1 m strip from seeded rows at 6 random locations in each pasture. Accompanying measurement of inter-row distance allowed calculation of herbage mass per unit area. Herbage samples were oven-dried (60°C), ground through a 1-mm screen, and analyzed for IVDMD using procedures modified from Moore and Mott (1974). Residues were not ashed and

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Table 1. Performance of cattle grazing rye pastures.

	Rye Entry		
	Wrens Abruzzi	Cycle 5	Cycle 7
1991-92, Heifers			
Initial wt (kg)	206	207	—
Daily gain (kg)	0.78	0.85	—
Carrying capacity (d ha^{-1})	564	548	—
Gain (kg ha^{-1})	440	464	—
1994-95, Steers			
Initial wt (kg)	269	—	270
Daily gain (kg)	1.28	—	1.26
Carrying capacity (d ha^{-1})	452	—	425
Gain (kg ha^{-1})	573	—	538

calculations were made on a dry matter, rather than a fresh organic matter, basis.

Data for each experiment were analyzed separately using analysis of variance. Animal performance data were cumulative for the entire grazing period. Sampling dates were included in the statistical models used to evaluate vegetation variables.

RESULTS AND DISCUSSION

Experiment 1

Heifers grazing either Wrens Abruzzi or cycle 5 rye achieved daily gains averaging 0.82 kg for 106 d (Table 1). Mean stocking rate was 5.3 heifers ha^{-1}. Kouka et al. (1994) predicted daily gains of 0.76 kg for heifers grazing rye for 110 d with a constant stocking rate of 4.9 heifers ha^{-1}. No differences in daily gains, carrying capacity or liveweight gain ha^{-1} could be attributed to rye germplasm.

Experiment 2

Steers gained an average of 1.27 kg daily during the second grazing experiment, lasting 90 d (Table 1). Neither daily gain, carrying capacity, nor total gain ha^{-1} were influenced by rye germplasm.

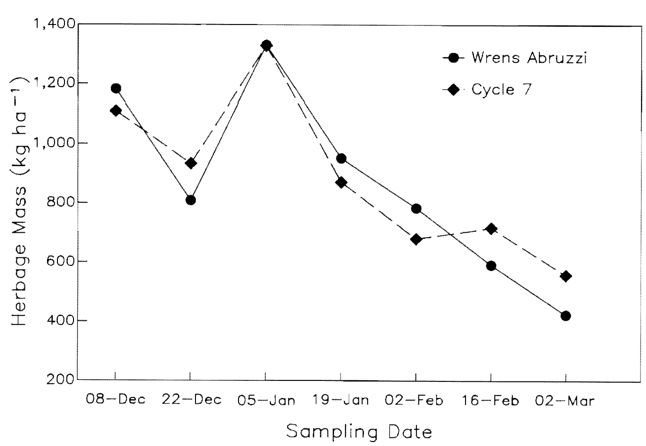

Fig. 1. Herbage mass of rye pastures grazed by steers during 1994-95 at Tifton, GA; RMSE = 369 kg ha^{-1}.

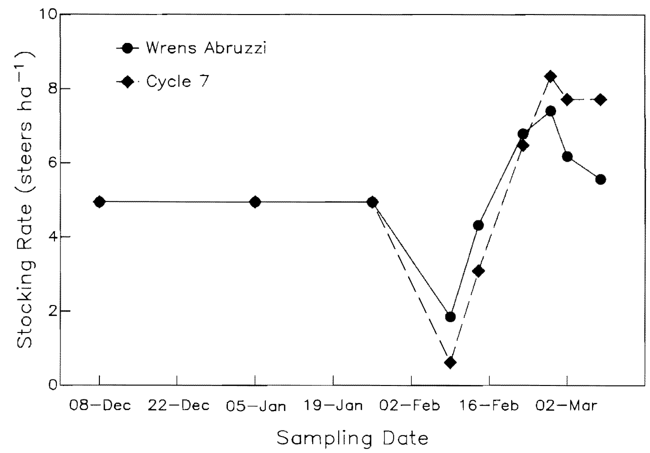

Fig. 2. Stocking rates resulting from addition and removal of put-and-take grazer steers from rye pastures during 1994-95 at Tifton, GA.

Herbage mass, monitored biweekly during 1994-95, declined from more than 800 kg ha^{-1} during December and January to ≈ 500 kg ha^{-1} by early March (Fig. 1), but was not different between rye entries. Stocking rates varied from less than 2 to more than 7 heifers ha^{-1}, but were not influenced by rye germplasm (Fig. 2). High final stocking rates led to the rapid decline in herbage mass as rye approached maturity. Dry matter concentration of forage on offer increased from ≈ 110 g kg^{-1} to 160 g kg^{-1} as the season progressed, but was not different between the rye germplasms (Fig. 3).

Digestibility of available forage declined from more than 800 g kg^{-1} initially to ≈ 620 g kg^{-1} in early March (Fig. 4). Cycle 7 forage on offer (751 g kg^{-1}) was more digestible ($P < 0.05$) than Wrens Abruzzi (738 g kg^{-1}). In spite of this slight digestibility advantage of cycle 7 forage, no differences in performance of weaned steers could be attributed to rye germplasm (Table 1). Excellent daily gains were supported by the rye forage. Utley et al. (1976) reported daily gains of about 1 kg for steers grazing rye. Higher performance in the second experiment might be attributed to genetic background of the cattle, implants, ionophore or some combination of these factors. Hill (1995) reported steer daily gains of 1.36 kg for

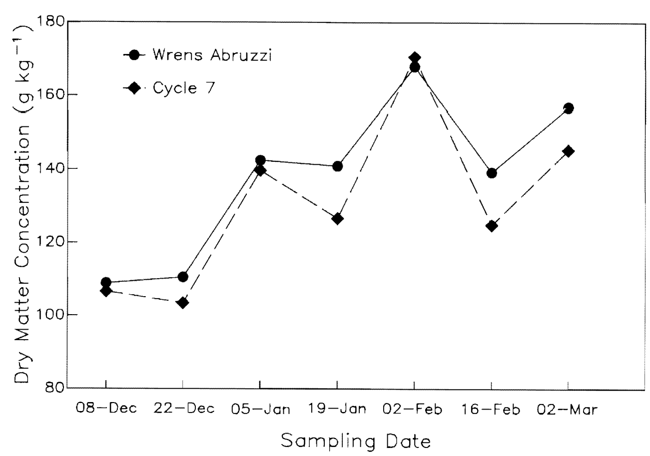

Fig. 3. Dry matter concentration of forage harvested from rye pastures grazed by steers during 1994-95 at Tifton, GA; RMSE = 18.8 g kg^{-1}.

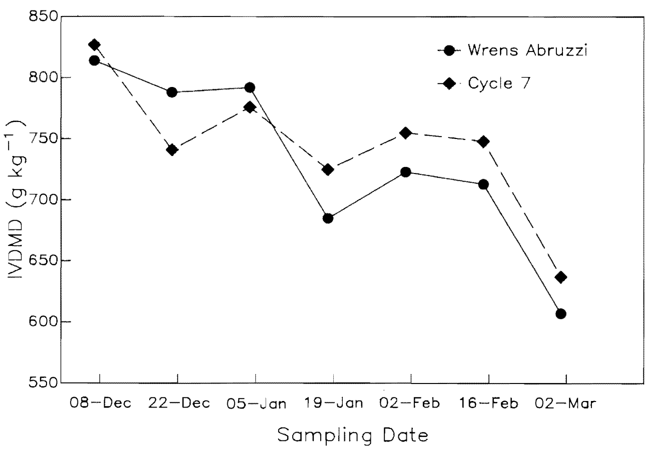

Fig. 4. IVDMD of forage harvested from rye pastures grazed by steers during 1994-95 at Tifton, GA; RMSE = 35.2 g kg^{-1}.

implanted steers grazing rye pastures for 113 d and fed a free-choice mineral containing ionophore. Likewise, there were no differences in carrying capacity nor gain ha^{-1} between rye germplasms. Carrying capacity, which was 30% greater in 1991-92, can be attributed primarily to using heifers which were nearly 30% lighter at the beginning of the experiment and which therefore grew at a slower rate. Smaller animals reduced the forage demand, allowing a 16 d longer grazing season.

CONCLUSIONS

Small dry matter yield advantages of selected rye germplasms, documented in clipping trials (Day et al., 1991; 1992; 1993; 1994; 1995), did not result in increased carrying capacity in either grazing trial nor in greater herbage mass, measured in the second grazing trial. Although cycle 7 forage was higher in digestibility than Wrens Abruzzi, daily gains were not different in either experiment. Presumably, with already high forage quality of rye, animal performance was not limited by energy concentration.

Little progress in improved animal production was realized from the rye selection procedures used. Continued selection, additional sources of genetic variation for yield, or modified selection procedures might allow sufficient increase in dry matter yield to improve animal production. Other traits such as disease resistance or seed yield and quality may be more critical to profitable production of winter pasture using rye. Selection for increased digestibility would not appear to be important, based on the lack of response to higher IVDMD observed in experiment 2.

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Influence of Summer Grass and Legume Crops on Winter-Grown Wheat and Lupin

P. J. Wiatrak*, D. L. Wright, D. W. Reeves, J. A. Pudelko, and B. Kidd

ABSTRACT

This research was conducted during 1994 and 1995 on a Dothan sandy loam (fine, loamy siliceous, thermic Plinthic Kandiudults) located at the North Florida Research and Education Center (NFREC), Quincy, FL. The objective of this research was to evaluate the influence of summer grass and legume crops on winter-grown wheat and lupin. Winter wheat (*Triticum aestivum* L.) (var. Coker 9835) and white lupin (*Lupinus albus* L.) (var. "Lunoble") followed tropical corn (*Zea mays* L.), pearl millet [*Pennisetum glaucum* (L.) R. Br., HGM™ 100] and soybean [*Glycine max* (L.) Merr.]. Four nitrogen rates (0, 67, 134 and 202 kg ha^{-1}) were applied to tropical corn and pearl millet. Higher yields of wheat silage [35% dry matter (DM)] in 1994 were obtained after tropical corn (14.3 t ha^{-1}) and soybean (13.3 t ha^{-1}) than after pearl millet (12.9 t ha^{-1}) but, in 1995, wheat silage (35% DM) yields were higher after soybean and pearl millet (15.3 t ha^{-1} and 14.4 t ha^{-1}, respectively). The N content of wheat silage in 1994 increased with previous N fertilization on rotation crops. Highest wheat grain yield (2.3 t ha^{-1}) in 1994 occurred after both tropical corn and soybean. In 1995, grain yields of wheat were generally lower than in 1994 and without significant effects from previous crops. The grain yield of wheat after tropical corn in 1994 was a linear function of N rate applied to tropical corn (0 to 202 kg N ha^{-1}). The N content of wheat grain in 1994 following tropical corn was highest at 125 kg N ha^{-1}. Nitrogen fertilization of previous rotation crops did not affect wheat grain yields in 1995. The 4.4 t ha^{-1} silage yield of white lupin in 1994 after soybean was higher than after tropical corn or pearl millet. In 1995 the highest yield of lupin silage (5.2 t ha^{-1}) was obtained after soybean. In 1994, the highest grain yield (1134 kg ha^{-1}) of white lupin was obtained after tropical corn, but in 1995 the previous-crop influence was not significant.

INTRODUCTION

White lupin is a high protein grain legume grown during the winter in the southern USA. Human food products such as pasta and flour are made from lupin (Ayisi et al., 1992). Fuentes et al. (1988) reported that the environment influenced lupin pod number and seed weight, but not seed number per pod. Perry and Poole (1975) reported that drought stress reduced the number of pods per plant. Farmers have used legume cover crops for many years as a green manure source for cultivated cropping systems (Hoyt, 1989) to increase qualities of biologically-fixed N and to recycle other plant-essential nutrients (P, K, Ca, Mg) in the soil.

Growth of legume cover crops depends upon geographic locations and climatic conditions (Hoyt and Hargrove, 1986). Cropping sequence also plays a major role in biomass and nutrient accumulation.

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Different crops can have different effects on soil structure (Reid and Goss, 1981). For example, soybean (*Glycine max* L.) tends to leave the soil more susceptible to wind and water erosion than corn (*Zea mays*) (Bathke and Blake, 1984). They concluded that different effects of soybean and corn on soil could be related to the effect either of the growing plants or of their remains on soil structure. Reeves et al. (1984) reported that differences between soils after wheat and those after a lupin crop with regard to soil water-stable aggregates and bulk densities were small and inconsistent.

A soybean/wheat double crop system consistently produced excellent wheat yields during the early years of study, but the yields of continuous systems have declined in recent years, probably as a result of disease buildup in the crops (Boquet and Coco, 1994). A cropping sequence in which wheat is planted every other year (1989, 1991, 1993) has yielded an average of 1.2 t ha^{-1} (18 bu acre^{-1}) higher than continuously cropped wheat. The double-crop soybean/wheat rotation also increased soil organic matter levels 19% higher than continuously cropped soybean.

The objective of this experiment was to study the influence of tropical corn, pearl millet and soybean (with different N rates on the tropical corn and pearl millet) on grain and silage yields of white lupin and wheat, and on N content in grain and silage of winter-grown crops.

MATERIALS AND METHODS

These studies were conducted on a Dothan sandy loam (fine, loamy siliceous, thermic Plinthic Kandiudults) located on the NFREC, Quincy, FL from 1993 to 1995. The soil has a compacted layer located 20 to 36 cm below the surface. The experiment was conducted for two years following cropping of tropical corn, pearl millet and soybean. The experimental design was a split-plot (main plots followed previous crops and sub-plots followed N fertilizer rates for the previous crops) with four replications. Wheat (var. Coker 9835) and lupin (var. "Lunoble") were used in this study. Preplant cultivation included s-tine chisel plowing, plowing (with switch-plow) and s-tine harrowing. Prior to planting, the wheat was fertilized with 672 kg ha^{-1} of 5-10-15 (N P K) material, and lupin was fertilized with 146 kg ha^{-1} of 0-46-0 (N P K) material and 168 kg ha^{-1} of 0-0-60 (N P K) material. The fertilizer was incorporated into the soil with an s-tine harrow.

Wheat was seeded at 101 kg ha^{-1} with an H & N cone drill (13 cm row width) and lupin was seeded at 78 kg ha^{-1} on 22 Nov. 1993 and 1994 with a KMC planter (91 cm row width). A rolling-cultivator was used to cultivate the middle of the rows in the lupin plots for weed control on 24 Jan. 1994 and 31 Jan. 1995. The wheat sections were sprayed with 2,4 D @ 1.8 L ha^{-1} on 27 Jan. 1994 and 22 Feb. 1995. On 4 Feb. 1994 and 3 Feb. 1995, wheat was

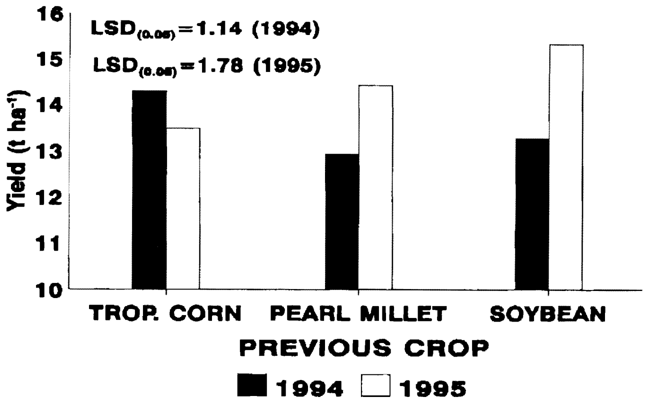

Fig. 1. Influence of previous crop on silage yield of wheat.

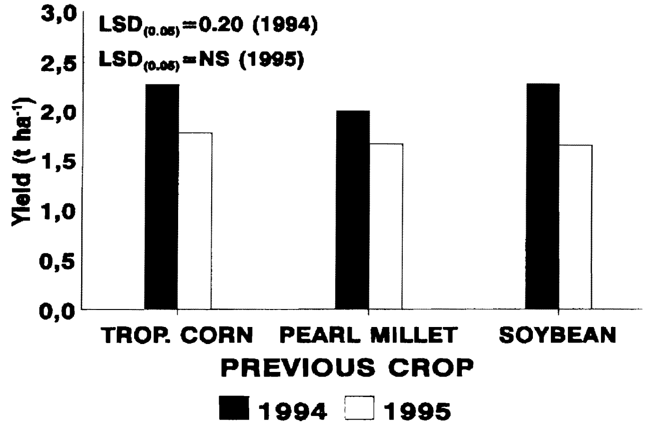

Fig. 3. Influence of previous crop on grain yield of wheat.

fertilized with 78 kg N ha^{-1} (34 0 0 N P K material) using a Gandy fertilizer spreader. Lupin and wheat were cut for silage on 6 May 1994 and 28 Apr. 1995. Wheat was harvested for grain on 23 May and lupin for grain on 10 June 1994 and on 19 May and 14 June 1995, respectively, using a Gleaner E combine.

Results of the experiment were analyzed statistically using SAS (SAS, 1989) by analysis of variance, and means were separated using Fisher's Least Significant Difference Test at the 5% probability level.

RESULTS AND DISCUSSION

The analyzed features were significantly different between 1994 and 1995; therefore, the data were not combined. The highest yield of 35% dry matter (DM) wheat silage (Fig. 1) in 1994 was obtained after tropical corn (14.3 t ha^{-1}), second highest after soybean (13.3 t ha^{-1}) and lowest after pearl millet (12.9 t ha^{-1}) but, in 1995, the trend was reversed with highest yield after soybean and second highest after pearl millet (15.3 and 14.4 t ha^{-1}, respectively). Percent N in wheat silage in 1994 was not significant with respect to a crop effect after tropical corn and pearl millet (Fig. 2); therefore, the data were combined. There was a positive linear response of % N in the wheat silage in 1994 to N rates on previous crops (0 to 202 kg N ha^{-1}). In 1995, the % N in wheat silage (Fig. 2) was not significantly different between tropical corn and pearl millet. The only increase in % N for wheat silage in 1995 was between the previous crop N rates of 134 kg ha^{-1} and 202 kg ha^{-1}.

The grain yield of wheat in 1994 (Fig. 3) was the same after tropical corn as after soybean (2.3 t ha^{-1}), but significantly higher than after pearl millet (2.0 t ha^{-1}). In 1995 (Fig. 3), the grain yields of wheat were lower than

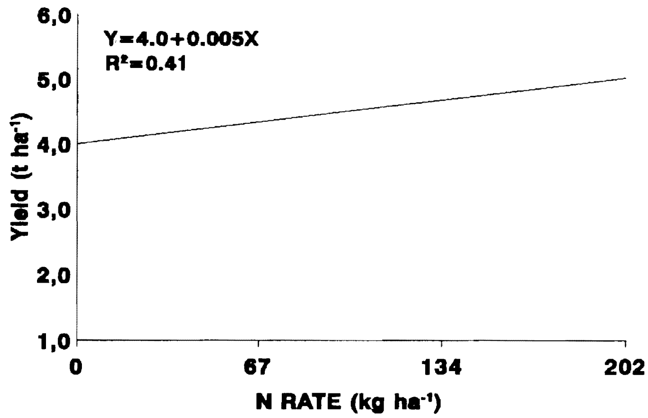

Fig. 4. Influence of N fertilization of tropical corn on grain yield of wheat during 1994.

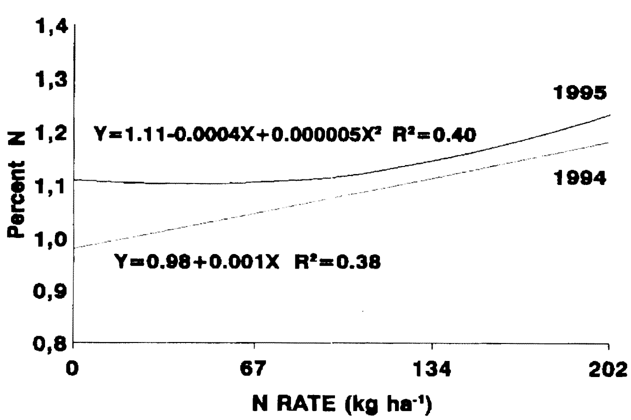

Fig. 2. Influence of N fertilization of tropical corn and pearl millet on N in wheat silage during 1994 and 1995.

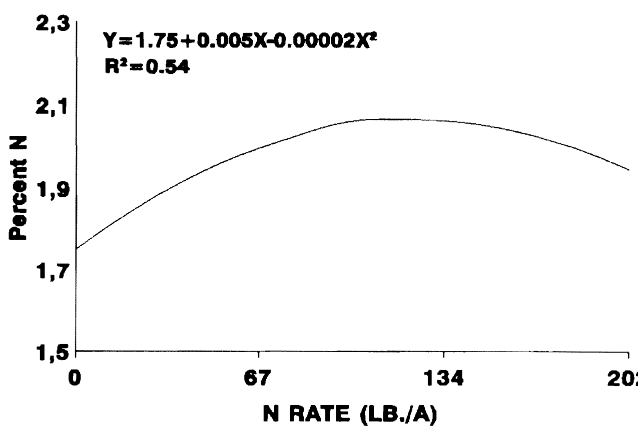

Fig. 5. Influence of N fertilization of tropical corn on N in wheat grain during 1994.

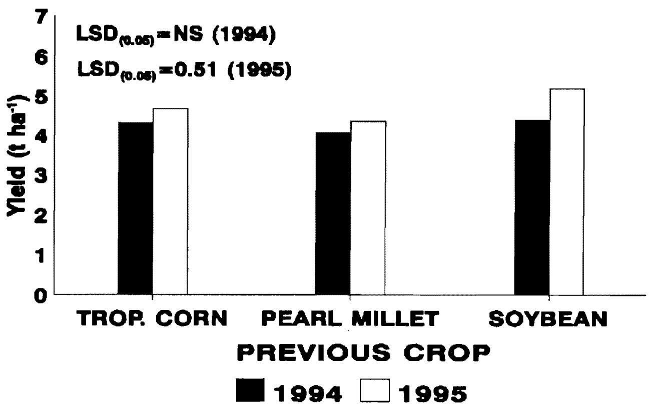

Fig. 6. Influence of previous crop on silage yield of white lupin.

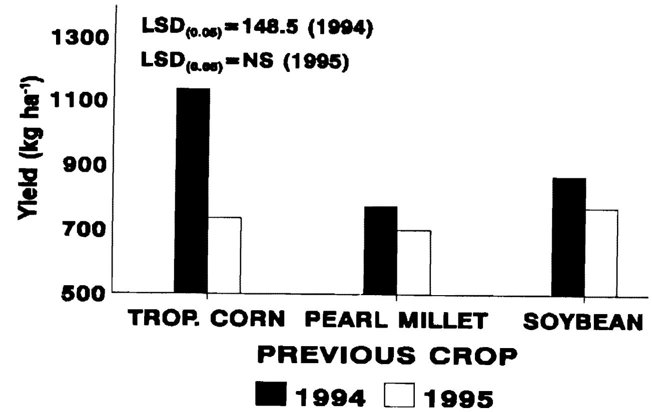

Fig. 7. Influence of previous crop on grain yield of white lupin.

in 1994 and without significant previous-crop effects on grain yield of wheat. The grain yield of wheat after tropical corn in 1994 (Fig. 4) was a positive linear function of N applied to the previous crop (over the range 0 to 202 kg N ha^{-1}).

The % N in wheat grain of wheat in 1994 after tropical corn (Fig. 5) was highest at 125 kg N ha^{-1} applied to the previous crop and lowest at 0 kg N ha^{-1}. There was not a significant difference for % N in wheat grain between different previous crops for 1995. The silage yield of white lupin in 1994 (Fig. 6) was not significantly different between previous crops. In 1995 (Fig. 6), the significantly highest yield of lupin silage was obtained after soybean (5.2 t ha^{-1}).

In 1994, the highest grain yield of white lupin (Fig. 7) was obtained after tropical corn (1134 kg ha^{-1}), but in 1995 the previous-crop effect was not significantly different. Higher rainfall in 1994 than in 1995 may have contributed to differences in wheat and lupin data between years.

In conclusion, increasing rates of N applied to previous crops generally increased silage and grain yield of wheat, and no previous summer crop stood out as superior prior to growth of wheat or lupin.

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Foliar Biostimulant, N and K Rate, and Cultivar Effects on Fresh Market Tomato

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ABSTRACT

The effect of two foliar-applied biostimulants, KeyPlex 350 and 'Tri-Ag', at two N plus K rates, 1× and 1.5× (1× = 195 N plus 324 K kg ha^{-1}), was evaluated with regard to growth and yield of two tomato, *Lycopersicon esculentum* Mill., cultivars (cvs.) 'Equinox' and 'Sunbeam'. The study was conducted during the spring (Feb-June) 1995 on an EauGallie fine sand (sandy, siliceous, hyperthermic Alfic Haplaquods). Production system was the full-bed polyethylene mulch with seepage (modified furrow) irrigation. Experimental design was a split-split plot arranged in a randomized complete block with four replications. Main plots were the two biostimulants and a water control, subplots were the N plus K rates, and sub-sub plots were the tomato cultivars. In the main plots the foliar sprays were applied at 6, 32, and 48 days after planting (DAP). Plant heights were affected by cultivars only. 'Equinox' plants were taller ($P \leq 0.01$) until 65 DAP than 'Sunbeam' plants but, at first harvest (81 DAP), 'Sunbeam' plants were 10.0 cm taller than 'Equinox' plants ($P \leq 0.01$). The 'Tri-Ag' biostimulant increased the yield of medium (57.2 - 64.3 mm diameter) fruits in the early harvest ($P \leq$ 0-01), but the seasonal yields of all fruit sizes were similar with either biostimulant or water treatments. The higher (1.5×) N plus K rate resulted in an increased yield of medium-size fruits ($P \leq$ 0.01). Early yields of 'Equinox' were higher than 'Sunbeam' yields ($P \leq 0.01$); however, for the season, 'Equinox' yields were higher only in the large (63.5 - 70.6 mm diameter) fruit size ($P \leq 0.05$). Macro- and microelement concentrations in tomato shoots and in fruits were similar with biostimulant or water treatments.

Tomato growers in Florida face an increasing competition for the marketshare by foreign suppliers, and are searching for ways to increase tomato fruit quality and yield in an economic manner. In average years, commercial freshmarket tomato profit is increased by earlier harvest, larger fruit size and higher yield. Biostimulants, containing phytohormones, α-keto acids, amino acids and humic acids with or without essential macro- and micronutrients, have been promoted to growers for the purpose of improving quality (fruit size) and quantity of vegetable yields. Manufacturers of the biostimulants claim that the products, when used as recommended, will increase nutrient uptake with resulting better plant growth and increased yields. Researchers in previous studies with biostimulants on vegetable crops found various degrees of success. For example, Bryan and Read (1971) reported a 56% increase in total tomato yields from α-keto acid-treated seedings compared to non-treated controls. In a study conducted for three consecutive seasons, Csizinszky (1986) found increased extra-large fruit yields of 'Key-Plex'- and 'Cytex'-treated 'Sunny' tomatoes compared to water-treated controls. On the other hand, Castro et al. (1988) for tomatoes, Albregts et al. (1988) for strawberries, Csizinszky (1990) for bell peppers, and Csizinszky et al. (1990) for micro-irrigated bell peppers and tomatoes reported similar yields with or without biostimulant treatments. Macro- and micronutrient concentrations in shoots and fruits were also similar with or without biostimulant treatments (Castro et al. 1988; Csizinszky, 1990; Csizinszky et al. 1990). Some biostimulant treatments, however, resulted in very high shoot concentrations for B, Cu, Mn and Zn at bloom and at fruit set that reduced fruit size and marketable yields (Csizinszky, 1986). The effect of biostimulants on tomatoes also depended on the cultivar (Csizinszky, 1986). 'Key Plex 350'- and 'Cytex'-treated 'Sunny' tomatoes had an increased yield of extra-large fruit compared to a water control, but yields of 'Hayslip' were similar, or lower, with biostimulants than with a water control.

This study was conducted to evaluate the effect of two foliar biostimulant products, at two N and K rates, on two new fresh-market tomato cultivars.

MATERIALS AND METHODS

The study was conducted during the winter-spring (Feb-June) of 1995 at the University of Florida Gulf Coast Research and Education Center on an EauGallie fine sand (sandy siliceous hyperthermic Alfic Haplaquods). Soil samples, taken prior to land preparation, were extracted with the Mehlich-1 extractant (Hanlon et al. 1990) and then analyzed for macro- and micronutrients. The soil had a water pH of 6.60 and (in mg kg^{-1}) 36.0 P, 20.0 K, 841.0 Ca, 151.0 Mg, 1.6 Cu, 7.7 Fe, 1.9 Mn, and 2.7 Zn. Nitrogen in the soil was determined by the Kjeldahl method (Tecator, Inc. 1987), with the concentration (in mg kg^{-1}) of NH_4-N being 1.2 and that of NO_3-N being 1.0. The experimental design was a split-split-plot arranged in a randomized complete block and replicated four times. Production system was the full-bed polyethylene mulch with seepage (modified furrow) irrigation. Main plots, 29 m long and 1.52 m wide, were two foliar biostimulants: 'KeyPlex 350' and 'Tri-Ag' (Table 1) and a water control. Subplots, 14.5 m × 1.52 m, were two N plus K rates: 195 N plus 324 K kg ha^{-1} (1×) and 293 N plus 486 K kg ha^{-1} (1.5×). Sub-sub plots, 7.25 m × 1.52 m, were two tomato cultivars: 'Equinox' and 'Sunbeam'. In the main plots the biostimulants were applied at 2.34 liters ha^{-1} in 300 liters of H_2O 3× during the season, on 22 Feb., 20 Mar., and 5 Apr., by a portable backpack sprayer with a hollow-cone nozzle at 28 kg cm^{-2} pressure.

In the sub-plots the N and K from a 15-0-25 (N-P-K) source was applied at two rates: 195 N plus 324 K kg ha^{-1} and 293 N plus 486 K kg ha^{-1}. The N and K fertilizer was placed in 5 cm deep 2.5 cm wide grooves formed 30 cm from the bed center on each half of the 83 cm wide and 20 cm high beds. Beds were formed on 1.52 m centers. Phosphorous from a 0-8.7-0 (N-P-K) superphosphate material was applied at 52 kg ha^{-1} for all treatments and was placed in a 15 cm wide band on the false bed prior

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Table 1. Composition of the Key Plex 350 and Tri-Ag biostimulants.

	Key Plex 350†	Tri-Ag
	g liter^{-1}	
N	—	5.64
P	—	2.46
K	—	4.68
Mg	19.77	5.64
S	52.73	—
B	2.11	—
Cu	0.08	—
Fe	46.14	0.56
Mn	9.89	0.56
Mo	0.04	—
Zn	9.89	1.24

†In addition to the elements listed on the label, this material also contains α-keto acids.

to actual bed formation. Soil was fumigated with a 66.6% methylbromide/33.3% chloropicrin mixture at 239 kg ha^{-1} (mulched-bed basis), and then covered with a 0.32 mm thick black polyethylene film. Two weeks later, on 16 Feb., 5-week old 'Equinox' and 'Sunbeam' tomato seedlings, obtained from a commercial source, were transplanted into the beds at 46 cm spacing in a single row. Transplants were treated with 'Admire' (imidacloprid) at 1.12 kg ha^{-1} for control of the silverleaf whitefly (*Bemisia argentifolii* Bellows and Perring). 'Admire' was dissolved in the transplant water. Lateral shoots growing from the lower 3 to 4 axillary buds were pruned on 13 Mar. Plants were staked and then tied three times during the season. Pesticides, labelled for tomatoes against insects, bacteria and fungi, were applied on a weekly preventative basis.

Plant heights for six plants in each sub-sub plot were measured at 26, 65 and 81 days after planting (DAP).

Soil samples for pH, total soluble salts and elemental analyses from each sub-plot were taken at 5 DAP, on 21 Feb., and from each sub-sub plot at 110 DAP (6 June). Soil samples were extracted using the Mehlich-1 extractant, and then analyzed for macro (N, P, K, Ca, Mg) and microelement (B, Cu, Fe, Mn, Zn) concentrations (Hanlon et al., 1990). Dry matter contents and elemental concentrations on recently matured young compound leaves were determined (Hanlon and DeVore, 1989) from each sub-sub plot at 39 (27 Mar.), 57 (14 Apr.), and 106 DAP (31 May). Fruits were harvested on 11, 18 and 25 May and on 6 June. At harvest, fruits were separated into marketable and cull (United States Department of Agriculture, 1981), with marketable fruits being size-graded as extra large (xlg): ≥ 70 mm; large (lg): 63.5-70.6 mm; and medium (med): 57.2-64.3 mm in diameter, by machine. Number and weight of fruit in each grade were recorded. On 30 May (105 DAP), fruit samples were taken from each sub-sub plot for dry matter determination and analyses of macro- (N, P, K, Ca, Mg) and microelements (B, Cu, Fe, Mn, Zn) (Hanlon and DeVore, 1989). Data were analyzed by ANOVA (SAS Institute, Inc. 1988).

Table 2. Plant height (cm) of 'Equinox' and 'Sunbeam' tomatoes on selected days after planting.

Cultivar	DAP†		
	26	65	81
	cm‡		
Equinox	25.5	77.8	102.0
Sunbeam	23.2	75.9	112.0
$LSD_{0.01}$	0.70	1.31	2.22

†DAP = days after planting.
‡Averaged over three spray treatments, 2 N plus K rates, and 4 replications.

RESULTS

Plant heights on each of the three planting dates were affected by cultivars only (Table 2). At 26 DAP 'Equinox' plants were taller than 'Sunbeam' plants ($P \leq 0.01$); however, as the season progressed, 'Sunbeam' plants grew more rapidly and, by 81 DAP, averaged 10 cm taller than 'Equinox' plants ($P \leq 0.01$).

Foliar sprays had little effect on fruit yields (Table 3). For the early harvests (harvests 1 and 2), weight (Mg ha^{-1}) of medium (57.2 - 64.3 mm diameter) and cull fruits were higher with 'Tri-Ag' than with 'Key-Plex 350' or water spray. Numbers of marketable fruits in the early harvest were also higher with 'Tri-Ag' than with 'KeyPlex 350' sprays ($P \leq 0.05$). For the season, weight and number of fruits in all grades were similar with the three foliar sprays (Table 3).

Nitrogen and K rates affected only the yield of medium size fruits, which were higher with the 1.5× than with the 1× N plus K rates (Table 4).

Cultivars had the greatest effect on early fruit yields (Table 5). 'Equinox' for the first two harvests in all grades gave higher yields than 'Sunbeam' ($P \leq 0.01$). For the season, however, 'Equinox' yields were higher than 'Sunbeam' yields only in terms of the weight and number of medium and cull grades and in the total number (marketable plus cull) of fruits harvested ($P \leq 0.01$).

Macroelemental concentrations in the shoots were similar for all three foliar spray treatments at the end of the season (104 DAP) (Table 6). Nitrogen, P and K concentrations were higher, and Ca concentrations were lower, in tissues at the 1.5× rate than at the 1× N plus K rate ($P \leq 0.05$) (Table 6). Among the cultivars, 'Equinox' had a higher concentration of dry matter and N and K, and a lower concentration of Ca and Mg, than 'Sunbeam' (Table 6). Micronutrient concentrations in shoots were similar for all three experimental factors (data not presented).

For the fruits, dry matter and macroelemental concentrations were similar with foliar-spray treatments (Table 7). There were higher concentrations of all macroelements with the higher (1.5×) N plus K rates than with the 1× N plus K rates ($P \leq 0.05$). 'Sunbeam' had higher N, P, K and Mg, and a lower concentration of Ca, in the fruit than 'Equinox' (Table 7). Microelement concentrations in the fruits were similar across spray treatments, N plus K rates, and cultivars (data not presented).

Table 3. Early and seasonal total yields of foliar biostimulant-treated tomatoes.

Fruit size and grade‡	Early yield†			LSD§	Seasonal total yield†			LSD§ Signif.
	Water	Key Plex 350	Tri-Ag		Water	Key Plex 350	Tri-Ag	
		Mg ha^{-1}				Mg ha^{-1}		
xlg	26.7	25.3	26.1	ns	61.8	58.7	57.1	ns
lg	9.8	8.8	10.2	ns	19.9	19.6	20.7	ns
med	3.5	3.4	4.6	0.55**	9.1	9.6	10.7	ns
marketable total	40.0	37.5	40.9	ns	90.8	87.9	88.5	ns
cull	3.6	4.4	4.7	0.86*	9.3	10.3	10.7	ns
marketable + cull	43.6	41.9	45.6	ns	100.1	98.2	99.2	ns
		no ha^{-1} (× 1000)				no ha^{-1} (× 1000)		
xlg	123.1	115.8	121.0	ns	284.3	268.4	266.0	ns
lg	63.6	54.9	66.1	ns	132.2	130.9	136.1	ns
med	29.8	27.7	38.0	7.19*	79.2	81.0	89.4	ns
marketable total	216.5	198.4	225.1	19.12*	495.7	479.3	491.5	ns
cull	28.1	32.4	38.7	5.85**	78.8	84.1	91.4	ns
marketable + cull	244.6	230.8	263.8	22.12**	574.5	563.4	582.9	ns

†Averaged over 2 N plus K rates, 2 cultivars, and 4 replications.
‡Fruit size: xlg = ≥ 70 mm; lg = 63.5-70.6 mm; med = 57.2-64.3 mm in diameter.
§LSD is significant at $P \leq 0.05$ (*); $P < 0.01$ (**); or non-significant (ns).

Table 4. Effect of N and K rates on weight and number of early tomato fruits.

Fruit size and grade‡	Early yield			Seasonal total yield		
	N + K rate†		LSD§	N + K rate†		LSD§
	1×	1.5×		1×	1.5×	
	Mg ha^{-1}¶			Mg ha^{-1}¶		
xlg	27.3	24.7	ns	60.8	57.6	ns
lg	9.6	9.6	ns	19.8	20.4	ns
med	3.4	4.2	0.64*	8.7	10.9	1.75**
marketable total	40.3	38.5	ns	89.3	88.8	ns
cull	4.2	4.2	ns	10.5	9.7	ns
marketable + cull	44.5	42.7	ns	99.8	98.5	ns
	no ha^{-1} (× 1000)			no ha^{-1} (× 1000)		
xlg	124.8	115.2	ns	280.6	265.3	ns
lg	61.4	61.6	ns	131.5	134.6	ns
med	28.9	34.7	ns	74.6	91.8	13.4*
marketable total	215.2	211.7	ns	486.7	491.6	ns
cull	30.5	35.6	ns	84.6	84.9	ns
marketable + cull	245.7	246.3	ns	571.3	576.5	ns

†N plus K rate: 1× = 195 kg N plus 324 kg K ha^{-1}.
‡Fruit size: xlg = ≥ 70.0 mm; lg = 63.5-70.6 mm; med = 57.2-64.3 mm in diameter.
§LSD is significant at $P \leq 0.05$ (*); or non-significant (ns).
¶Averaged over 3 spray rates, 2 cultivars, and 4 replications.

In the soil, residual concentrations of NH_4- and NO_3-N and K increased with N plus K rate and were also higher after 'Equinox' than after 'Sunbeam' plants (Table 8). Residual micronutrient concentrations in the soil were similar with all three experimental factors (data not presented).

DISCUSSION

Under the excellent growing conditions during spring 1995 foliar biostimulants compared to a water control, and the 1.5× N plus K rates compared to the 1× N plus K rates, evidenced little benefit on size and quantity of tomato fruits. The negligible benefit of foliar biostimulants on vegetable and strawberry yields in seasons when growing conditions were normal and moisture and nutrient levels were adequate have been demonstrated in several previous studies (Albregts et al., 1988; Castro et al., 1988; Csizinszky et al., 1990). Only when biostimulant studies were conducted over consecutive seasons, in which growing conditions varied and plants were under stress due to environmental effects or poor

Table 5. Effect of cultivars on weight and number of tomato fruits.

Fruit size and grade‡	Early yield†			Seasonal total yield†		
	Equinox	Sunbeam	LSD§	Equinox	Sunbeam	LSD§
	Mg ha^{-1}			Mg ha^{-1}		
xlg	30.1	21.9	3.28**	57.1	61.3	ns
lg	12.1	7.1	1.03**	21.2	19.0	1.85*
med	4.8	2.8	0.74**	10.1	9.5	ns
marketable total	47.0	31.8	3.35**	88.4	89.8	ns
cull	6.2	2.2	0.61**	12.2	8.0	0.82**
marketable + cull	53.2	34.0	3.52**	100.6	97.8	ns
	no ha^{-1} (× 1000)			no ha^{-1} (× 1000)		
xlg	140.4	99.6	14.21**	265.9	279.9	ns
lg	77.7	45.4	7.48**	140.3	125.7	12.47*
med	39.5	24.1	6.44**	86.5	79.9	ns
marketable total	257.6	169.1	17.76**	492.7	485.6	ns
cull	46.8	19.3	4.48**	98.0	71.6	10.96**
marketable + cull	304.4	188.4	19.62**	590.7	557.2	25.87**

†Averaged over 3 spray rates, 2 N plus K rates, and 4 replications.
‡Fruit size: xlg = ≥ 70.0 mm; lg = 63.5-70.6 mm; med = 57.2-64.3 mm in diameter.
§LSD is significant at $P \leq 0.05$ (*); $P \leq 0.01$ (**); or non-significant (ns).

soil, did foliar- or soil-applied biostimulants have beneficial effects on yields (Bryan and Read, 1971; Csizinszky, 1986; Csizinszky, 1990).

The high early-season yields of 'Equinox' and the high yield of 'Sunbeam' in the later harvests point to the importance of the proper selection of cultivars by growers who have to fill market demands throughout the season.

Macroelement concentrations in the shoots and in the fruits were all in the sufficiency range; therefore, the differences in macroelement concentrations of the tissues with N plus K rates and between cultivars did not affect yields. Similarly, differences in soil residual concentrations of NH_4- and NO_3-N and K were small, and the quantity of nutrients remaining in the soil would have some importance only when fertilizer re-

Table 6. Dry matter content and macroelement concentrations in tomato shoots at 104 DAP.†

Treatment	DM	N	P	K	Ca	Mg
	g (100 g)$^{-1}$					
Foliar spray‡						
H_2O	14.51	2.99	0.24	3.09	3.04	0.83
Key Plex 350	14.52	2.76	0.24	3.20	2.96	0.82
Tri-Ag	14.47	2.98	0.25	3.11	3.17	0.83
$LSD_{0.05}$§	ns	ns	ns	ns	ns	ns
N plus K rate¶						
1×	14.45	2.43	0.23	2.69	3.44	0.83
1.5×	14.55	3.39	0.26	3.57	2.67	0.82
$LSD_{0.05}$§	ns	0.245	0.013	0.181	0.308	ns
Cultivar#						
Equinox	14.81	3.24	0.25	3.27	2.99	0.81
Sunbeam	14.19	2.58	0.24	2.99	3.12	0.84
$LSD_{0.05}$§	0.27	0.191	ns	0.198	ns	0.029

†DAP = days after planting.
‡Averaged over two N plus K rates, two cultivars, and 4 replications.
§LSD is significant at $P \leq 0.05$ (as indicated) or non-significant (ns).
¶Averaged over three foliar spray treatments, two cultivars, and 4 replications. 1× N plus K = 195N plus 324K kg ha^{-1}.
#Averaged over three foliar spray treatments, two N plus K rates, and 4 replications.

Table 7. Dry matter content and macroelement concentrations in tomato fruit at harvest.

Treatment	DM	N	P	K	Ca	Mg
	g (100 g)$^{-1}$					
Foliar spray†						
H_2O	6.10	2.30	0.50	4.03	0.11	0.22
Key Plex 350	5.99	2.21	0.50	4.10	0.11	0.22
Tri-Ag	6.16	2.17	0.48	3.96	0.11	0.20
$LSD_{0.05}$‡	ns	ns	ns	ns	ns	ns
N plus K rate§						
1×	6.14	2.07	0.48	3.84	0.10	0.21
1.5×	6.03	2.39	0.51	4.22	0.12	0.22
$LSD_{0.05}$‡	ns	0.156	0.016	0.135	0.011	0.009
Cultivar¶						
Equinox	6.08	2.14	0.46	3.88	0.12	0.20
Sunbeam	6.09	2.32	0.53	4.18	0.10	0.22
$LSD_{0.05}$‡	ns	0.179	0.030	0.157	0.010	0.009

†Averaged over two N plus K rates, two cultivars, and 4 replications.
‡LSD is significant at $P \leq 0.05$ (as indicated) or non-significant (ns).
§Averaged over three foliar spray treatments, two cultivars, and 4 replications. 1× N plus K rate = 195N plus 324K kg ha^{-1}.
¶Averaged over three foliar spray treatments, two N plus K rates, and 4 replications.

Table 8. Residual concentrations of macronutrients in the soil.

Treatment	pH	NH_4	NO_3	P	K	Ca	Mg
		g (100 ml)$^{-1}$					
Foliar spray†							
H_2O	7.19	0.76	0.68	58.2	33.5	1140.0	238.0
KeyPlex 350	7.34	0.75	0.77	59.9	27.2	1155.0	239.0
Tri-Ag	7.38	0.72	0.40	59.3	32.9	1136.0	235.0
$LSD_{0.05}$‡	0.146	ns	ns	ns	ns	ns	ns
N and K rate§							
1×	7.28	0.71	0.10	60.4	20.3	1151.0	236.0
1.5×	7.32	0.77	1.31	57.9	45.0	1137.0	239.0
$LSD_{0.05}$‡	ns	0.128	0.96	ns	15.12	ns	ns
Cultivar¶							
Equinox	7.30	0.84	1.08	59.9	39.9	1122.0	230.0
Sunbeam	7.30	0.64	0.27	58.4	24.3	1166.0	245.0
$LSD_{0.05}$‡	ns	0.128	ns	ns	6.68	ns	ns

†Averaged over two N plus K rates, two cultivars, and 4 replications.
‡LSD is significant at $P \leq 0.05$ (as indicated) or non-significant (ns).
§Averaged over three foliar spray treatments, two cultivars, and 4 replications.
¶Averaged over three foliar spray treatments, two N plus K rates, and 4 replications.

quirements for a second crop following tomatoes were calculated.

In summary, due to the favorable growing conditions during this study in the spring of 1995, foliar biostimulant treatments and N plus K rates, above 195 N and 324 K kg ha^{-1}, had little or no beneficial effects on tomato fruit size and marketable yields. Of the two cultivars, 'Equinox' had higher yields than 'Sunbeam' in the early harvests (harvests 1 and 2) and 'Sunbeam' yields were higher than 'Equinox' yields later in the season (harvests 3 and 4). This difference in earliness between the cultivars may be used by growers to plan fruit supply for the market throughout the season.

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Influence of Grazing Frequency on Production and Quality of *Paspalum*, *Brachiaria*, and *Setaria* Grasses

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ABSTRACT

Bahiagrass (*Paspalum notatum* Flugge) is the most popular perennial forage grass in Florida. However, its limitations include poor forage production when temperatures are cool and day length is short, low quality forage, and stand loss due to mole crickets (*Scapteriscus* spp.). The purpose of this experiment was to screen three bahiagrasses, four *Brachiaria* spp., and a *Setaria* cultivar at four grazing frequencies (GF) for dry matter (DM) yield, quality, total non-structural carbohydrates (TNC), and persistence. Experimental design was a split-plot arrangement of a randomized complete block with three replicates of GF (2, 3, 5, and 7 wk) as main plots and grass entries (Pensacola, Tifton-9, and Cycle-18 bahiagrass; *B. brizantha* cv. Marandu, *B. decumbens*, *B. ruziziensis*, and *B. humidicola*; and Setaria cv. Kazungula) as subplots. Crude protein (CP) and in vitro organic matter digestion (IVOMD) were monitored in the spring of 1994 (following December to April forage accumulation), and in June-July, August-September, October, and December for 1992 and 1993. Total non-structural carbohydrates were monitored at the beginning of the study and during December of each year. Annual fertilization was 170-15-57 kg ha^{-1} N-P-K plus 1.7 kg ha^{-1} Cu, Zn, Mn, and Fe and 3.4 kg ha^{-1} S, with N split in March, July, and September. Warm season (May-December) DM yield of grass entries interacted with GF when pooled over 3 yr. *Brachiaria decumbens*, Cycle-18, and Tifton-9 bahiagrasses were among the highest DM yielders at all GF when pooled over 3 yr, and also expressed the greatest DM decline between year 1 and year 3 at all GF. *Brachiaria humidicola* and Tifton-9 performed most favorably, with an overall increase in DM between year 1 and 3. Generally, CP was higher in bahiagrass than *Brachiaria* forage and IVOMD higher in *Brachiaria* than bahiagrass forage. In general, *B. humidicola* produced good DM yields of quality forage and persisted well under the wet (often saturated) soil conditions of central Florida.

Bahiagrass is the most popular perennial forage grass in Florida, occupying ≈ 70% of the improved pastures. Once established, bahiagrass persists under continuous close grazing even if fertilization is omitted for 1 to 2 yr, making the grass popular among commercial growers. This warm-season grass generally initiates spring growth in March and continues producing forage through October (Mislevy and Brown, 1991). Little to no forage is produced between November and early March, forcing cattlemen to feed hay and/or supplemental feed. Bahiagrass produces DM yields averaging 9 to 10 Mg ha^{-1} (Mislevy et al., 1983) with low fertility requirements. Forage quality (CP and IVOMD) of bahiagrasses are less than those of Digitgrass, stargrass, or bermudagrass (Mislevy et al., 1982). Recently, considerable area has been lost to mole crickets, causing commercial growers to consider other options regarding low input, perennial, pasture grasses.

In recent years, mass selection modified by restrictions has improved Recurrent Restricted Phenotypic Selection (RRPS) (Burton, 1982) and has been applied to bahiagrass breeding. These restrictions make RRPS more efficient than mass selection for increasing Pensacola bahiagrass forage yields. The RRPS that required 3 yr per cycle in 1960 has been improved to permit one cycle per year, with the same increase in yield per cycle. Through the RRPS mass selection system, seed for testing was available for cycles 9 (Tifton-9 released, Burton, 1989) and 18 (Cycle-18 not officially released). In addition to the new bahiagrasses, several *Brachiaria* grasses are being offered for sale in central Florida. Little or no data are available on these entries.

The purpose of this experiment was to use the mob-grazing technique to screen three bahiagrass entries, four *Brachiaria* spp., and a *Setaria* cultivar at grazing frequencies of 2, 3, 5, and 7 wk for yield, quality, TNC, and persistence.

MATERIALS AND METHODS

The experiment was established on a sandy, siliceous, hyperthermic Ultic Haplaquod (Pomona fine sand) in late July of 1991 and conducted from 1992 to 1994 at the Univ. of Florida, Range Cattle Research and Education Center, Ona, FL. Test entries were seeded on a well prepared, moist, seed bed. The grass entries tested, and seeding rates, consisted of Tifton-9 (11 kg ha^{-1}), Pensacola (39 kg ha^{-1}) and Cycle-18 bahiagrass (9 kg ha^{-1}); *B. decumbens*, *B. humidicola*, *B. brizantha* cv. Marandu, and *B. ruziziensis* (5.6 kg ha^{-1}); and *S. sphacelata* cv. Kazungula (17 kg ha^{-1}). Two bahiagrass entries, Tifton-9 and Cycle-18, are RRPS-derived from Pensacola and were developed at the Coastal Plain Experiment Station, Tifton, GA. Cycle-18 is an experimental line that has not yet been released. All entries were compared with Pensacola bahiagrass as the commercial standard.

Nitrogen (N) was applied 30 d after seeding at a rate of 65 kg ha^{-1}, followed by a second application of 56 kg ha^{-1} in mid-October to encourage plant establishment. In March of each year 15 kg ha^{-1} P and 57 kg ha^{-1} K were applied, plus 1.7 kg ha^{-1} Cu, Zn, Mn, and Fe in sulfate form and 3.4 kg ha^{-1} S. A total of 170 kg ha^{-1} N was applied in three equal applications (March, July and September). Soil Ca averaged 800 mg kg^{-1} and Mg averaged 110 mg kg^{-1}, as determined by the Mehlich I (0.05 *M* HCl and 0.01 *M* H_2SO_4) procedure (Southern Cooperative Series, 1984), with an average soil pH of 6.7.

Experimental design was a split plot arrangement of a RCB, with 3 replications. Grazing frequencies of 2, 3, 5, and 7 wk were main plots, with the eight grass entries as subplots. Each subplot measured 7.5 by 7.5 m. A 0.6

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m border surrounding each subplot was maintained free of vegetation by repeatedly using glyphosate [N-(phosphonomethyl) glycine] at a 3% concentration in 188 L water ha^{-1}.

Grazing season was from May to December, 1992 through 1994. Prior to grazing a strip of forage, 0.5 by 3.0 m, was harvested from each subplot to a stubble height of 7.5 cm in order to determine DM yield. Crude protein and IVOMD samples were obtained by hand clipping to a 7.5-cm stubble height. Each main plot consisted of a fenced paddock within which cattle were allowed to randomly graze all entries. Eight crossbred two-year-old steers (100 ha^{-1}) were allowed to consume (mob graze) forage to a 5- to 10-cm stubble range within a 1- to 2-d period. Cattle were then removed from each main plot and a 0.6- by 6.0-m strip was mowed again to 7.5 cm to remove residue in each subplot. This area within the plot was marked and then resampled for DM yield and quality (if required) at the next harvest. The strip was rotated to a new sample site in each subplot for residue removal and a future sampling of DM and quality. Percentage ground cover (GC) occupied by common bermudagrass [*Cynodon dactylon* (L.) Pers. var *dactylon*] was estimated visually at the beginning of the experiment and in December of each year.

Crude protein and IVOMD of harvested forage were monitored as follows: 1) after winter-spring (90 d in December-March 1993 and 120 d in December-April 1994) forage accumulation, 2) at time of harvesting in early summer (June-July), 3) in late summer (August-September), 4) in early fall (October), and 5) in late fall (December). Forage DM yields were determined at the end of the winter-spring (90 d in 1993 and 120 d in 1994) season. Additional harvests at 2, 3, 5, and 7 wk were pooled for the warm season (May-December) to obtain total seasonal DM yield. These were also pooled over years. Forage samples were dried at 60°C, ground, and analyzed for total N (Gallaher et al., 1975; Hambleton, 1977) and IVOMD (Moore and Mott, 1974). Crude protein content was calculated as 6.25 × N.

Total nonstructural carbohydrates in the crown region were monitored at the beginning of the experiment and in the fall of each year. Two core samples (10-cm diameter) of grass crowns were removed from each subplot prior to grazing, in order to monitor TNC concentration (g kg^{-1}). Each core was sampled to a depth of 7.5 cm and shoots (stubble) were cut to a height of 7.5 cm (crown). Samples were immediately washed to remove soil and debris, heated to 100°C for 1 hr, and subsequently dried at 60°C in a forced-draft oven. Dried tissue was weighed, ground to pass a 1-mm screen, sealed in plastic bags, and stored in a freezer along with silica-gel desiccant. Extraction of TNC from ground tissue followed the enzymatic procedure modified by Smith (1981). The extract was analyzed for reducing sugars using Nelson's (1944) colorimetric adaptation of Somogyi's (1945) copper-reduction method, with glucose standards. Total non-structural carbohydrate yield was obtained as: g = g kg^{-1} TNC × crown mass.

A pooled-year analysis for DM yield and forage quality (May-December) was conducted to determine long-term effects of the significant GF × grass entry interactions. A significance level of 0.05 was used for all F-tests. Differences among means for non-continuous variables that occurred in interactions were investigated using Duncan's Multiple Range Test, along with regression equations for continuous variables. Differences among non-continuous variables that were independent of GF were investigated using the Waller-Duncan procedure at k = 100.

RESULTS

Forage DM Production

Warm-season DM yield of grass entries interacted with GF when pooled over a 3-yr period. This interaction provided information on which entries should have the greatest yield over three years at a particular GF, along with the relationship of GF to yield of a particular grass entry (Table 1). *Brachiaria decumbens* and Cycle-18 bahiagrass generally produced highest DM yields, averaging 9.2 and 8.5, 9.0 and 9.4, 10.1 and 12.8, and 19.0 and 14.8 Mg ha^{-1} at GF of 2, 3, 5, and 7 wk, respectively.

Table 1. Influence of grass entry by grazing frequency on warm season (May-December) dry matter yield, pooled over 3 yr.

Grass entry	Grazing frequency (wk)				Regression equations
	2	3	5	7	
	Mg ha^{-1}				
Bahiagrass					
Pensacola	6.7 bc*	7.6 ab	10.1 b	12.2 ef	4.97 + 1.01W[†]
Tifton-9	8.5 a	8.5 a	10.3 b	13.0 c-e	6.17 + 0.907W
Cycle-18	8.5 a	9.4 a	12.8 a	14.8 b	5.81 + 1.319W
Brachiaria					
B. decumbens	9.2 a	9.0 a	10.1 b	19.0 a	$16.17 - 4.876W + 0.752W^2$
B. brizantha	7.8 ab	6.3 b	9.2 bc	14.8 bc	$11.78 - 3.167W + 0.513W^2$
B. ruziziensis	6.0 c	6.0 b	8.5 bc	12.5 d-f	$6.73 - 0.88W + 0.246W^2$
B. humidicola	5.8 c	6.0 b	8.1 c	13.7 b-d	$8.126 - 1.895W + 0.381W^2$
Setaria	4.3 d	4.0 c	6.3 d	10.5 f	$5.79 - 1.413W + 0.297W^2$
Avg.	7.2	7.2	9.4	13.7	

*Means within columns followed by different letters are significantly different at the 5% level (Duncan's Multiple Range Test).
[†]W = grazing frequency (wk).

Table 2. Dry matter yield of grass entries and yield change from 1992 to 1994 as influenced by grazing frequency.

	Grazing frequency (wk)											
	2			3			5			7		
Grass entry	1992	1994	Change	1992	1994	Change	1992	1994	Change	1992	1994	Change
	----- Mg ha⁻¹ -----		%	----- Mg ha⁻¹ -----		%	----- Mg ha⁻¹ -----		%	----- Mg ha⁻¹ -----		%
Bahiagrass												
Pensacola	5.8 c*	7.8 bc	+34	7.8 a	7.2 a-c	−9	11.4 ab	7.6 a	−33	11.6 b	9.4 b	−19
Tifton-9	7.2 bc	10.5 a	+46	7.4 a	8.7 a	+18	10.8 ab	8.7 a	−19	13.4 b	10.8 ab	−20
Cycle-18	10.5 ab	6.9 bc	−34	8.7 a	8.3 ab	−5	14.8 a	9.4 a	−36	16.8 b	11.4 ab	−32
Brachiaria												
B. decumbens	10.9 a	8.5 ab	−22	9.2 a	7.8 ab	−15	11.9 ab	9.6 a	−19	25.5 a	11.4 ab	−55
B. brizantha	10.1 ab	6.7 bc	−34	8.1 a	4.9 c	−39	11.6 ab	7.4 a	−37	25.1 a	6.9 c	−72
B. ruziziensis	6.9 bc	5.8 c	−16	5.8 a	6.3 bc	+8	9.2 b	8.7 a	−5	14.6 b	9.2 b	−37
B. humidicola	5.4 c	7.4 bc	+38	4.9 a	6.5 a-c	+32	9.2 b	7.6 a	−17	16.8 b	12.1 a	−28
Setaria	8.1 a-c	4.7[1]	−42[2]	6.3 a	6.0	−4	10.8 ab	8.1	−25	16.4 b	15.0	−8
Avg.	8.1	7.6	−6	7.3	7.1	−3	11.2	8.4	−25	17.5	10.1	−42

*Means within columns followed by different letters are significantly different at the 5% level (Duncan's Multiple Range Test).
[1]Means are from 1993, since entry died after 2 yr due to insect problems.
[2]Percentage change between 1992 and 1993; not included in overall average.

Generally, DM yields of Pensacola bahiagrass used as a commercial standard were not different ($P>0.05$) from those for *B. ruziziensis* or *B. humidicola.* Unlike *Cynodon* spp. (Mislevy et al., 1983), *Brachiaria* and *Paspalum* entries grazed at a 2- and 3-wk frequency had similar DM yields, averaging 7.2 Mg ha^{-1}. As GF was delayed from 2 or 3 wk to 5 wk, DM yield increased by 30% and from a 5- to 7-wk GF by another 46%. On average, DM yields for the bahiagrasses and *Brachiaria* grasses increased 30 and 34% as GF was delayed from 3 to 5 wk. However, delaying grazing frequency from 5 to 7 wk increased DM yield by 21 and 66% for the bahiagrasses and *Brachiaria* grasses, respectively (Table 1). Dry matter yields of the *Setaria* entry used in this study were quite low, possibly due to damage by the 'Two-Lined' spittle bug [*Prosapia bicincla* (Say)] and 'Southern' chinch bug (*Blissus insularis*). Both insects were observed on *Setaria* during the summer of 1993, resulting in chlorotic and necrotic areas within the plant stand.

Dry matter production of most grasses tends to decrease following the first harvest year after establishment, regardless of GF. Average DM production across all entries decreased by 6, 3, 25, and 42% from year 1 (1992) to year 3 (1994) for the 2-, 3-, 5-, and 7-wk GF, respectively (Table 2). All grasses tested in this study decreased in DM production over time at the 5- and 7-wk GF. *Brachiaria decumbens*, Cycle-18 bahia, and *B. brizantha* also declined considerably in DM production at GF of 2 and 3 wk between 1992 and 1994. When comparing all grass entries across all GF, Tifton-9 bahia and *B. humidicola* performed the best, with an overall positive change in forage yield from 1992 to 1994 (Table 2). The decline in forage yield by *B. decumbens, B. brizantha,* and Cycle-18 bahiagrass between 1992 and 1994 is due to the lack of persistence of these entries.

Tropical grasses generally produce a major portion of their DM yield during the warm-wet season (Mislevy and Everett, 1981). During the cool and/or dry season, forage production is limited. Yield of dry forage during the 1992-93 (90 d) and 1993-94 (120 d) cool seasons differed ($P < 0.05$) between grass entries, which was independent of GF. On average, *B. decumbens,* Cycle-18 bahia, *B. brizantha,* and Tifton-9 bahiagrass yielded 183, 150, 50, and 50% (1.9, 1.7, 1.0, and 1.0 Mg ha^{-1}) higher DM during the cool season than Pensacola bahiagrass, respectively (Table 3). However, *B. humidicola* yielded 33% less DM than Pensacola during the same period. This confirmed the poor cool-season growth characteristics of *B. humidicola* previously reported by Mislevy and Everett (1981).

Percentage ground-cover increase by common bermudagrass was affected ($P < 0.05$) by grass entry. Common bermudagrass GC increase was highest for the *Setaria,* averaging 88% increase (average over all GF) above the 2.7% GC at the start of the experiment (Table 4). This large increase for common bermudagrass in the *Setaria* was the result of stand losses, possibly due to

Table 3. Dry matter yield of tropical grasses during the cool seasons of 1992-93 and 1993-94.[1]

Grass entry	1992-93[1] (90 d)	1993-94 (120 d)	Average
	-------------	Mg ha⁻¹	-------------
Bahiagrass			
Pensacola	0.2 d*	1.1 c	0.7
Tifton-9	0.4 cd	1.6 b	1.0
Cycle-18	1.1 b	2.2 a	1.7
Brachiaria			
B. decumbens	2.0 a	1.8 b	1.9
B. brizantha	0.9 bc	1.1 c	1.0
B. ruziziensis	0.4 cd	0.9 cd	0.7
B. humidicola	0.4 cd	0.4 d	0.4
Setaria	0.7 bc	—	0.3

*Means within columns followed by different letters are significantly different at the 5% level (Waller-Duncan procedure at k = 100).

[1]Cool season during the respective years was between December and March (90 d) and December and April (120 d).

Table 4. Influence of grass entry by grazing frequency on increase of common bermudagrass (CB) under grazing over a 3-yr period.

Grass entry	Initial CB	Grazing frequency (wk) 2	3	5	7	Regression response
	% GC[1]	--- Percentage unit increase ---				
Bahiagrass						
Pensacola	3.3 de*	4 c	6 cd	−2 c	−1 cd	NS[2]
Tifton-9	7.8 b-d	9 c	7 cd	11 c	−3 cd	NS
Cycle-18	5.1 c-e	63 b	44 b	7 c	25 bc	*
Brachiaria						
B. decumbens	8.3 bc	18 c	23 bc	48 b	31 b	NS
B. brizantha	9.2 bc	21 c	7 cd	43 b	15 b-d	NS
B. ruziziensis	10.8 ab	21 c	18 b-d	61 b	37 ab	NS
B. humidicola	15.1 a	−6 c	−12 d	−13 c	−13 d	NS
Setaria	2.7 e	96 a	96 a	94 a	66 a	*

*Means within columns followed by different letters are significantly different at the 5% level (Duncan's Multiple Range Test).

[1]GC = ground cover.

[2]NS = not significant.

Table 5. Crude protein (CP) and in vitro organic matter digestion (IVOMD) of eight grass entries harvested at four accumulation periods and pooled over 2 yr.

Grass entry	Forage accumulation periods June-July	Aug.-Sept.	Oct.	Dec.
	CP, g kg^{-1}	--------- IVOMD, g kg^{-1} ---------		
Bahiagrass				
Pensacola	104 a*	522 e	547 e	—
Tifton-9	100 b	545 d	576 d	561 de
Cycle-18	101 ab	537 de	568 d	567 d
Brachiaria				
B. decumbens	93 c	630 b	711 a	702 a
B. brizantha	101 ab	626 b	692 a	656 b
B. ruziziensis	95 bc	660 a	694 a	623 b
B. humidicola	88 c	599 c	662 b	627 c
Setaria	101 ab	592 c	628 c	655 b

*Means within columns followed by different letters are significantly different at the 5% level (Waller-Duncan procedure at k = 100).

damage from the Two-Lined spittle bug and/or the Southern chinch bug, as discussed earlier.

Grazing Cycle-18 at a 2- or 3-wk frequency was detrimental to stand persistence, resulting in a 63 and 44 percentage unit increase for common bermudagrass, respectively. Delaying the GF from 3 to 5 wk was beneficial to the persistence of Cycle-18, because common bermudagrass GC increased by only 7 percentage units in 3 yr. These data indicate that Cycle-18, unlike Pensacola and Tifton-9, will not tolerate frequent grazing.

Influence of GF on *B. ruziziensis, B. brizantha,* and *B. decumbens* was found to be the opposite of effects observed for most grasses, showing highest persistence when GF is most rapid at 2 or 3 wk. Delaying GF of these three *Brachiaria* grasses to 5 or 7 wk may allow plants to develop an oversupply of forage, which shades the stem bases and reduces the regenerative buds.

Brachiaria humidicola, unlike most of the other grasses tested in this study, was unaffected by GF (Table 4), while GC of common bermudagrass decreased at all GF. This low common bermudagrass GC may be why DM yield for *Brachiaria humidicola* was among the highest of all entries at the 7 wk GF in 1994 (Table 2).

Forage Quality

When pooled over 2 yr, there was a GF × grass entry interaction ($P < 0.05$) for both CP and IVOMD at selected growth periods. Crude protein concentration was not affected by GF during the June-July growth period (Table 5) and only varied due to grass entry. Generally, bahiagrasses contained higher concentrations of CP than *Brachiaria* grasses, with *B. humidicola* averaging only 88 g kg^{-1}. This CP value for *B. humidicola* was much lower than the 150 g kg^{-1} obtained by Mislevy and Everett (1981); however, N-fertilizer rates were 166% higher in the earlier study.

Crude protein concentration of forage accumulated during the August-September and October periods interacted ($P < 0.05$) with GF. Concentration of CP in the bahiagrasses, harvested during the August-September period, was generally higher than CP in the *Brachiaria* grasses (Table 6). This pattern tended to persist through all GF. Mean CP values for *B. humidicola* were always lower than CP values for the other *Brachiaria* spp., *Setaria,* and bahiagrasses. Regardless of grass entry, CP concentration decreased as GF was delayed from 2 to 7 wk. *Brachiaria decumbens* and *B. ruziziensis* both decreased in CP concentration by 3.63 g kg^{-1} wk^{-1} as GF was delayed. In contrast, CP concentration in the bahiagrasses decreased 6.7 g kg^{-1} wk^{-1}, which was about double the effect for the *Brachiaria* spp. (Table 6).

Crude protein concentration in October-harvested forage, as for many grasses (Mislevy et al., 1991; Mislevy et al., 1994), increased 31, 33, 41, and 35% above August-September values for 2-, 3-, 5- and 7-wk GF, respectively (Table 7). The main reason for higher CP is reduced plant growth due to shorter days and lower temperatures. In addition, with drier edaphic conditions in October, better soil N utilization is obtained, resulting in less DM and higher N content. Differences ($P < 0.05$) were obtained between entries at each GF; however, no one grass appeared to dominate in forage quality over all GF. Crude protein concentration in October forage of *B. humidicola* was lower ($P < 0.05$) than for the other grasses tested when grazed at the 2-wk frequency. Mean CP values for the 3-, 5-, and 7-wk frequencies were also the lowest numerically for *B. humidicola,* but statistically not different from values for many other entries. Crude protein of *B. decumbens* and Pensacola, Tifton-9, and Cycle-18 bahiagrass decreased an average of 5.7 g kg^{-1} wk^{-1} with GF during October, with *B. humidicola* decreasing ≈ 3.1 g kg^{-1} wk^{-1} with GF.

For IVOMD, GF did not interact with grass entry for the August-September, October, and December growth periods. However, grasses did differ ($P < 0.05$) in IVOMD during these periods (Table 5). Generally IVOMD was higher ($P < 0.05$) for *Brachiaria* entries than for bahiagrasses. During the August-September growth period, *Brachiarias* averaged 630 g kg^{-1} whereas bahiagrasses av-

Table 6. Crude protein as influenced by grass entry and grazing frequency (GF) for Aug.-Sep. accumulated forage, pooled over 2 yr.

Grass entry	Grazing frequency (wk) 2	3	5	7	Regression equations
	g kg⁻¹				
Bahiagrass					
Pensacola	128 a*	106 ab	98 a	80 b	139.1 - 8.5W[1]
Tifton-9	117 ab	113 a	92 ab	86 ab	129.6 - 6.48W
Cycle-18	115 ab	107 ab	91 ab	90 ab	122.3 - 5.1W
Brachiaria					
B. decumbens	100 b	103 ab	89 ab	85 ab	109.1 - 3.48W
B. brizantha	114 ab	89 bc	93 ab	86 ab	$279.3 - 133.7W + 29.6W^2 - 2.1W^3$
B. ruziziensis	107 b	93 b	86 ab	86 ab	109.2 - 3.78W
B. humidicola	82 c	73 c	79 b	78 b	NS[2]
Setaria	104 b	102 ab	89 ab	102 a	NS

*Means within columns followed by different letters are significantly different at the 5% level (Duncan's Multiple Range Test).
[1]W = GF in weeks.
[2]NS = not significant.

Table 7. Influence of grass entry by grazing frequency (GF) on October crude protein forage concentration pooled over 2 yr.

Grass entry	Grazing frequency (wk) 2	3	5	7	Regression equations
	g kg⁻¹				
Bahiagrass					
Pensacola	145 ab*	137 ab	124 cd	122 ab	152.1 - 4.76W[1]
Tifton-9	144 ab	145 a	125 b-d	114 a-c	160.9 - 6.73W
Cycle-18	140 b	137 ab	120 cd	113 a-c	151.9 - 5.74W
Brachiaria					
B. decumbens	161 a	142 ab	131 a-d	128 a	165.8 - 5.9W
B. brizantha	157 ab	126 bc	138 a-c	113 a-c	$395 - 198.3W + 46.3W^2 - 3.4W^3$
B. ruziziensis	152 ab	116 c	142 ab	109 bc	$462.3 - 262.7W + 63.2W^2 - 4.7W^3$
B. humidicola	118 c	114 c	115 d	100 c	125.1 - 3.17W
Setaria	140 b	133 ab	148 a	115 a-c	$243.2 - 9.37W + 25.3W^2 - 2.1W^3$

*Means within columns followed by different letters are significantly different at the 5% level (Duncan's Multiple Range Test).
[1]W = GF in weeks.

eraged 530 g kg⁻¹. This 100 g kg⁻¹ difference between the two grass genera continued into both the October and December accumulation periods. Since persistence may be a problem for *B. ruziziensis*, *B. brizantha*, and *B. decumbens* in central Florida, *B. humidicola* may be the only *Brachiaria* that is a viable alternative to bahiagrass in order to produce higher quality forage during the warm season.

In vitro organic matter digestion of forage harvested during the June-July growth period interacted with GF. Digestibility of *Brachiaria* entries continued to average about 100 g kg⁻¹ above bahiagrass entries, regardless of GF (Table 8). Delaying GF from 2 to 7 wk, for both the *Brachiaria* and bahiagrass entries, resulted in a linear decrease in IVOMD for all entries except *B. brizantha* and *Setaria*, which followed a cubic and a quadratic relationship, respectively. When GF was delayed from 5 to 7 wk, IVOMD of both the *Brachiaria* and bahiagrass entries declined dramatically. Similar results were reported by Mislevy et al. (1982) for members of the *Cynodon, Digitaria,* and *Paspalum* genera.

Forage CP concentration and IVOMD of grass entries harvested during the cool season were independent of GF. Crude protein and IVOMD of *Brachiaria* forage were higher ($P < 0.05$) than for forage from the bahiagrasses (Table 9). Generally, little difference was found between *B. ruziziensis*, *B. brizantha*, and *B. decumbens* with respect to either CP or IVOMD. *Brachiaria humidicola* forage was lower ($P < 0.05$) in CP than *B. ruziziensis* and *B. brizantha*, and the lowest for all *Brachiarias* in terms of forage IVOMD. However, these values were still 11 and 127 g kg⁻¹ higher for CP and IVOMD, respectively, than for Pensacola bahiagrass.

Crown Total Non-Structural Carbohydrates

Initial TNC concentration found in the crown of grass entries was independent of GF. The bahiagrasses and *B. ruziziensis* had a higher ($P < 0.05$) TNC concentration, averaging 8.3 g kg⁻¹; whereas *B. brizantha*, *B. humidicola*, *B. decumbens*, and *Setaria* averaged 5.5 g kg⁻¹ (data not shown).

Following 3 yr of grazing, TNC concentration of grass entries interacted with GF. At the 2-, 3-, and 5 -wk GF, TNC concentration averaged 9.5, 9.6, and 12.7 g kg⁻¹ for the bahiagrasses and *B. ruziziensis*. These grasses con-

Table 8. In vitro organic matter digestion as influenced by grass entry and grazing frequency (GF) of June-July accumulated forage, pooled over 2 yr.

Grass entry	Grazing frequency (wk)				Regression equations
	2	3	5	7	
	g kg⁻¹				
Bahiagrass					
Pensacola	575 f*	581 c	573 d	528 cd	603.8 - 9.3W[1]
Tifton-9	593 ef	586 c	580 d	514 d	631.2 - 14.8W
Cycle-18	616 e	593 c	577 d	518 d	653.3 - 18.2W
Brachiaria					
B. decumbens	720 bc	700 ab	670 ab	584 ab	779.3 - 26.1W
B. brizantha	764 a	691 ab	698 a	600 ab	$1297.7 - 441.8W + 103.1W^2 - 7.74W^3$
B. ruziziensis	740 ab	716 a	693 a	610 a	794.6 - 24.6W
B. humidicola	688 cd	661 b	646 bc	563 bc	738.1 - 23.2W
Setaria	676 d	674 b	613 cd	519 d	$662.2 + 19.4W - 5.71W^2$

*Means within columns followed by different letters are significantly different at the 5% level (Duncan's Multiple Range Test).
[1]W = GF in weeks.

tinued to have a higher ($P < 0.05$) TNC concentration than the other three *Brachiaria's*, which averaged 3.2, 3.0, and 3.7 g kg⁻¹ for the 2, 3, and 5 wk GF, respectively. This pattern continued into the 7 wk GF; however, only the bahiagrasses continued to be significantly higher in TNC concentration, with the *Brachiarias* averaging only 5.1 g kg⁻¹. The TNC yield was also calculated for each grass entry; however, no meaningful, detectable, relationships were evident.

SUMMARY

All grasses produced moderate to high DM yields during the three years (two years for *Setaria*) of the study. Forage IVOMD for the *Brachiaria* spp. generally was excellent, and generally higher than for the bahiagrasses during the warm and cool-season growth periods. However, CP of *Brachiaria* forage was generally lower than that obtained for the bahiagrasses.

The major concern with *B. brizantha, B. ruziziensis, B. decumbens*, Cycle-18 and Setaria was lack of persistence as evidenced by declining DM yield between year 1 and year 3 of the study. One possible reason for the lack of stand persistence may have been the harvest of each treatment to a 7.5-cm stubble height at each GF. Observations indicated that persistence of *B. decumbens* and *B. brizantha* tended to decrease following each harvest-sample removal to 7.5 cm, indicating that these grasses may not be adapted to clipping at that stubble height. Cycle-18 appeared to have a weak root system, with 4 times the amount of up-rooted crowns on the soil surface compared to the other grasses following grazing.

Of the new entries tested, *B. humidicola* appears to have the greatest potential to persist under close grazing and saturated-soil conditions. Data suggest that this entry is very persistent, with increased ground cover in competition with common bermudagrass resulting in nearly 100% *B. humidicola* stands. This grass also produces forage that averaged 90 g kg⁻¹ higher IVOMD, but 20 g kg⁻¹ lower CP, than Pensacola bahiagrass.

Table 9. Influence of grass entries on in vitro organic matter digestion (IVOMD) and crude protein (CP) of forage accumulated during the cool season (Dec.-April) 1993-94.

Grass entry	CP	IVOMD
	g kg⁻¹	
Bahiagrass		
Pensacola	111 d*	559 d
Tifton-9	100 e	543 d
Cycle-18	84 f	525 e
Brachiaria		
B. decumbens	126 bc	725 ab
B. brizantha	133 ab	719 b
B. ruziziensis	141 a	739 a
B. humidicola	122 c	686 c

*Means within columns followed by different letters are significantly different at the 5% level (Waller-Duncan procedure at k = 100).

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Evaluation of *Desmodium* Species Hybrids for Dry Matter and Seed Yield

K. H. Quesenberry* and D. E. Moon

ABSTRACT

Carpon desmodium [*Desmodium heterocarpon* (L.) DC] is adapted to pasture conditions in southern Florida, but the cultivar 'Florida' has received only limited producer acceptance, possibly due to low seedling vigor and susceptibility to root-knot nematodes, *Meloidogyne* species. A breeding program was initiated in 1983 to incorporate variability for these traits from plant introductions into selected lines which retain the desirable characteristics of the released cultivar. A group of F_4 and F_5 lines were developed with apparent improved root-knot nematode resistance and stand persistence, based on greenhouse and field selection nursery results. These lines were evaluated for seed production, forage dry matter yield, and persistence in three field experiments at Gainesville. Seed production was evaluated in Exp. 1 during 1991 and 1992. Dry matter yield and persistence were evaluated in two separate experiments, Exp. 2 conducted from 1991 to 1993, and Exp. 3 conducted from 1992 to 1994. Two lines were identified which were consistently superior to 'Florida' and the other breeding lines evaluated. Seed yields ranged from 10 to 400 kg ha^{-1} in 1991. Dry matter yields in Exp. 2 ranged from 2410 to 3000 kg ha^{-1} in 1991, 390 to 5630 kg ha^{-1} in 1992, and 0 to 3360 kg ha^{-1} at midseason 1993, when the test was terminated. Dry matter yields in Exp. 3 ranged from 4250 to 9190 kg ha^{-1} in 1993, and 490 to 9920 kg ha^{-1} in 1994. The two breeding lines also exhibited significantly greater persistence than 'Florida' into the third growing season of each test. Limited quantity of seed from these lines will be available for regional evaluation in 1996.

The legume species *Desmodium heterocarpon* (L.) DC (carpon desmodium) has been used successfully as a component of warm season perennial pastures in Florida. Currently only the cultivar 'Florida' (Kretschmer et al., 1979) is available for producers and it has found limited producer use. This cultivar is somewhat susceptible to root-knot nematodes but there is a wide range of variability within *D. heterocarpon* for response to root-knot nematodes (Quesenberry and Dunn, 1987). Interspecific hybridization between *D. heterocarpon* and *D. ovalifolium* Wall. for the purpose of incorporating the higher levels of root-knot nematode tolerance found in *D. ovalifolium* into a desirable *D. heterocarpon* agronomic type has been reported (Quesenberry et al., 1989). Results showed a low level of success in hybridization of the two species. Nevertheless, through careful selection of easily identifiable characteristics such as leaf markings and flower color, the number of hybrids identified could be increased. Other research showed that species hybrids had relatively high fertility and that advanced generation progeny were also fertile (McKellar and Quesenberry, 1992).

Nematodes may not be a limiting factor for production and persistence of this legume at all pasture sites, but improved establishment and persistence would likely increase producer acceptance. Small seed size and the associated low seedling establishment vigor may also limit acceptance of carpon desmodium. Only limited variability in seedling establishment was observed during evaluation of a range of germplasm (Quesenberry et al., 1989). In North-central Florida, stands of Florida carpon desmodium may be reduced by below-freezing temperatures, but variability in cold tolerance was observed during germplasm evaluation and parents were selected to possibly incorporate this trait. In South Florida, evaluation of 55 germplasm accessions of *D. heterocarpon* over a 3-yr period revealed marked variability in flowering date, flower color, leaf marking, and leaf area. Survival of several of the germplasm entries under grazing was superior to that for 'Florida' (Kretschmer et al., 1990). In this same report, persistence under grazing was evaluated over a 5-yr period, and percentage of plants alive at 5 yr after establishment ranged from zero to > 80%. These results also suggest that variability for agronomically important traits exists in the germplasm, which could be incorporated into a cultivar with attributes superior to those for 'Florida'. The objective of the current research was to assess progress in selecting for improvements in seed yield, dry matter production, and persistence for lines resulting from these crosses.

GERMPLASM DEVELOPMENT

A genetic improvement program began in 1983 with attempts to hybridize three *D. heterocarpon* geno-

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types with three *D. ovalifolium* genotypes. One cross (UF160 × UF144, *D. ovalifolium* × *D. heterocarpon*) resulted in three hybrid F_1 plants (83-3-3, 83-4-2, 83-4-3). Both of these parents have purple flowers and no leafmarks but UF160 is a low-growing, late-flowering type with moderate to high root-knot nematode resistance, whereas UF144 is an upright, early-flowering, root-knot-nematode-susceptible type. One of the F_1 plants, 83-4-2, was used as a female parent in 1985 crosses with IRFL6142, which is purple-flowered, leafmarked, and moderately to highly resistant to root-knot nematodes. All but two of the breeding lines tested in this report originated from the 83-4-2 × IRFL6142 cross. The remaining two lines were selections from a cross of UF160 × 'Florida' carpon desmodium. Spaced-plant selection nurseries were planted in 1986, 1987, and 1988, and limited selection was practiced in the F_2 and F_3 generations for general vigor and seed maturation prior to frost.

In 1989, a spaced-plant nursery of F_2, F_3, and F_4 generations from the above crosses was established. Seeds were collected in the fall of 1989 to produce two F_3 and 18 F_4 lines which were used for a 1990 F_3 and F_4 spaced-plant nursery. The 1990 selection nursery was in a field with high root-knot nematode populations so that concurrent selection for nematode resistance occurred.

MATERIALS AND METHODS

From the 1990 spaced-plant selection nursery, five F_4 lines (Entries 1, 2, 11, 12, and 14) were identified and seed was harvested as an F_5 bulk of each line for evaluation. Also in 1990, thinly-seeded rows of F_3 and F_4 selections, identified in 1989, were planted in a heavily root-knot-nematode-infested field on the Gainesville campus Agronomy farm, to evaluate these lines for nematode resistance. From this evaluation, one F_5 line (23) and four F_4 lines (17, 18, 19, and 20) were selected as resistant to the root-knot populations present in this field. Using either the bulked F_4 and F_5 seeds of the above 10 lines or remnant 1989 seeds, these 10 entries were then planted in 1991 as Exp. 1, a seed production experiment. Also included as entries in Exp. 1 were two additional F_4 and two F_5 individual plant selections from 1990. Those lines for which sufficient seed was available (primarily the 1990 bulks) were also planted as Exp. 2, a seeded-row forage dry matter yield experiment. Four of the nine F_5 bulk lines from 1990 (1, 2, 11, and 14) were among the top 12 in seed production for Exp. 1. These four lines, along with one F_5 line (23) and three F_4 lines (17, 18, and 19) selected for high root-knot nematode resistance in 1990 were then planted in 1991 as Exp. 3, a seeded, small-plot, forage dry matter yield trial.

All three experiments were conducted at the Dairy Research Unit (DRU) of the University of Florida near Hague, FL on a Sparr fine sand (loamy, siliceous, hyperthermic, Grossarenic Paleudults). The experimental design for Exp. 1 was a randomized complete block with two replications of the 14 entries described above and using Florida carpon as a comparison standard. Plots were 1.8-m wide by 15-m long with one plant every 0.3-m in the row and 0.9-m between rows for a total of 100 plants in each replication. Seeds were germinated and planted in greenhouse flats and then transplanted to the field in early June 1991. Flowering was estimated as a percentage on a weekly basis beginning in late August. All seeds were collected by hand during December 1991. Seeds were threshed using a huller-scarifier and cleaned using screens and a seed blower.

The experimental design for Exp. 2 was a randomized complete block design with four replications. Treatments consisted of thinly-seeded rows of eight of the 14 lines from Exp. 1 and 'Florida' carpon desmodium as a comparison standard. There were two rows of each line per plot. Plots 4.5-m long and 1.0-m wide with 0.5-m between rows were direct-seeded with a belt seeder on 5 June 1991. Forage dry matter yield data were obtained for the 1991, 1992, and 1993 growing seasons, with ratings for persistence made in the spring of 1994. Only one dry matter yield harvest was made each year. The first year's harvest was near frost at the end of the growing season on 14 Nov. 1991. The second year's harvest took place earlier, on 24 Aug. 1992. Although regrowth occurred after this date, it was left unharvested to provide reserves for winter persistence. A final harvest of those entries which had persisted into the third year was made on 30 July 1993.

The experimental design for Exp. 3 was a randomized complete block of 12 entries replicated four times. In addition to the eight lines indicated above, this experiment also included three lines selected from a 1991 spaced-plant nursery and 'Florida' carpon desmodium as a comparison standard. Each plot was 4.5-m long by 1.1-m wide with six seed-drilled rows on 15-cm centers. Plots were seeded on 26 June 1992, but forage dry matter yields were only determined for the 1993 and 1994 growing seasons. Ratings for persistence were made in June 1995.

RESULTS AND DISCUSSION

Experiment 1

There was significant variability in seed production among entries in 1991, with a range of 10 to 400 kg ha^{-1} (Table 1). 'Florida' carpon desmodium had higher seed yields than any of the selected lines in 1991. The highest yielding breeding selections in 1991, with yields exceed-

Table 1. Seed yield of selected *Desmodium* lines in Experiment 1.

Cultivar or Breeding lines	1991 Seed yield	1992 Estimated seed†
	kg ha^{-1}	
'Florida'	400 A‡	1.0
14	260 B	1.5
2	200 B	2.5
11	160 BC	1.5
1	70 CD	1.5
12	10 D	2.0

†0-4 rating scale: 0 = no seed production, 4 = very good seed production on surviving plants.

‡Means followed by the same letter are not significantly different, $P > 0.05$, Duncan's new multiple range test.

Table 2. Forage dry matter yield of selected *Desmodium* lines in Experiment 2.

Cultivar or Breeding lines	Forage dry matter yields			Persistence 6/94†
	11/91	8/92	7/93	
	kg ha⁻¹			
'Florida'	2410 A*	390 B	0 B	0.00 C
2	2430 A	5590 A	3360 A	3.00 AB
14	3000 A	5350 A	2930 A	4.00 A
11	2600 A	5230 A	2300 A	2.00 B
1	2590 A	5630 A	2280 A	2.75 AB

†0-9 rating scale: 0 = dead, 9 = complete, weed-free stand.

*Means within a date followed by the same letter are not significantly different, $P > 0.05$, Duncan's new multiple range test.

ing 200 kg ha^{-1}, were 2 and 14. Date of flowering for individual plants within entries ranged from 15 August to 1 October, with most entries reaching greater than 90% flowering by 25 September. Seed production was not quantified in the second year, but visual estimations of seed yields indicated that the level of variation observed during the first year continued in the second year, although the rankings for some entries changed (Table 1). 'Florida' carpon, the highest seed producer the first year, was among the poorest in seed yield estimates during the second year, due to poor stands resulting from winterkilling and lack of persistence.

Experiment 2

'Florida' carpon desmodium ranked near the bottom for dry matter yield in 1991, but there were no significant differences among entries (Table 2). Yield ranged from 2410 to 3000 kg ha^{-1}, with an average of 2610 kg ha^{-1}. In 1992, however, differences among entries were pronounced, with five of the selected lines yielding from 5230 to 5630 kg ha^{-1} while 'Florida' carpon yielded only 390 kg ha^{-1}. This low yield is attributable to the death of most plants during spring of the second year. By the third year, plots of 'Florida' carpon and one breeding line no longer had any plants alive, although none of the entries received a persistence rating above 4 on a 0 to 9 scale. Average yield of the surviving entries on 30 July 1993 was 2710 kg ha^{-1}. Two of the breeding lines, 2 and 14, surpassed this average by 210 and 650 kg ha^{-1}, respectively.

Experiment 3

In 1993, two of the breeding selections (2 and 14) had numerically higher yields but, due to high replication variability, were not statistically different from those for 'Florida' carpon desmodium. Yields ranged from 4250 to 9190 kg ha^{-1} (Table 3). By the end of the 1994 growing season, however, 'Florida' carpon desmodium was the lowest yielding entry, with only scattered plants surviving the winter. Entry 2, which had the highest

Table 3. Forage dry matter yield of selected *Desmodium* lines in Experiment 3.

Cultivar or Breeding lines	Dry matter yields		Persistence 1995†	Height 5/95
	1993	1994		
	kg ha⁻¹			
'Florida'	8140 AB*	490 B	2.25	3.5
2	8740 AB	9920 A	4.00	8.8
14	9190 A	6490 A	1.75	8.2
11	4250 B	6830 A	3.25	9.0
1	6870 AB	8330 A	3.25	10.8

†0-9 rating scale: 9 = all plants surviving; 0 = none.

*Lines with the same letter are not significantly different, $P < 0.05$, Duncan's new multiple range test.

yields in 1993, was also the highest yielding in 1994. Isolated plants of 'Florida' carpon desmodium could still be found in some plots during 1994, but persistence of the breeding selections was much higher. Plot survival ratings taken in June 1995, and plant height measurements, both indicated superior stand persistence (through three winters) and vigor for the new selections.

CONCLUSIONS

Two breeding lines selected on the basis of dry matter yields, high seed production, and persistence under cutting were identified for advanced line evaluation in regional trials. These two lines also show a much higher tolerance to root-knot nematode pressure under field conditions, have a more upright growth habit, and have produced much higher dry matter yields in the second and third years following planting than the cultivar 'Florida'. Both lines have violet purple flower color similar to that for 'Florida'. In separate research conducted during 1995, seed supply of these lines was increased and will be made available for testing starting in 1996.

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Delayed Anthesis in Sorghum under Low Nitrogen Availability

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ABSTRACT

Sorghum (*Sorghum bicolor* L. Moench) is a major crop in many regions of the world, especially where rainfall may limit the length of the growing season. Therefore, matching the length of plant development of sorghum with precipitation patterns is an important consideration. This study was undertaken to determine the extent to which soil N applications might influence sorghum development patterns, and particularly anthesis date. Three sets of field experiments were undertaken to examine changes in anthesis date in response to differing levels of N application under well-watered conditions. In most tests, treatments without the application of N had anthesis dates that were delayed up to 20 d relative to the well-fertilized treatments. In a study of vegetative development, it was found that a delay in leaf development and panicle exersion also occurred under low levels of N application. In a few cases, however, low levels of N application resulted in delayed anthesis of only 2 to 4 d. In these latter cases, it was hypothesized that mean daily temperature was an over-riding factor that prevented an expression of the delay in anthesis as a result of low soil N availability.

The timing of various ontological events in crop production is important in matching plant development with seasonal weather variations. The timing of anthesis and crop maturity are of particular interest. This is a special problem for sorghum (*Sorghum bicolor* L. Moench), because sorghum is commonly grown under arid conditions where it is critical to have plant development completed while there is still available water.

Temperature, as indexed by accumulated thermal units or growing-degree days, has been found to have marked effects on sorghum development (Arkin et al., 1976; Gerik and Miller, 1984; Muchow and Carberry, 1990). Hammer et al. (1989) reported a curvilinear response in development rate to temperature that included an optimum temperature. The derived optimum temperatures for maximum development rate ranged between 27 and 33°C, depending on cultivar. Development rate decreased to zero at temperatures of 35°C or greater. However, Hammer et al. (1989) presented few experimental data that were obtained at temperatures greater than 30°C.

Photoperiod has also been shown to influence sorghum development rate (Gerik and Miller, 1984; Hammer et al., 1989; Muchow and Carberry, 1990). Increased daylengths, especially greater than 13 h (Hammer et al., 1989), resulted in decreased rates of plant development.

One factor which has not been considered explicitly for its effect on sorghum development rate is the availability of soil N. In one of two years of experimentation, LaFitte and Loomis (1988) observed that sorghum anthesis was delayed by 7 d in a treatment with no N application. Muchow (1988) reported, for a sorghum crop sown on 29 January at Katherine, Australia (lat. 14° 28' S), that the length of the period from sowing to anthesis was 69.5, 62.3, and 60.3 d for N application treatments of 0, 6, and 12 g N m^{-2}, respectively. The delay in anthesis date associated with low N applications was subsequently confirmed by Muchow (1990) for a 30 August sowing of grain sorghum at Katherine. The period from sowing to anthesis was 70.0 and 61.5 d for N application treatments of 0 and 6 g N m^{-2}, respectively. Muchow (1990) reported, for an identical experiment sown on 28 February at the same site, that only a 2.6 d delay occurred in the 0 g N m^{-2} treatment as compared to the 6 g N m^{-2} treatment.

Delayed anthesis in sorghum as a result of low soil fertility is associated with markedly delayed maturity (Muchow, 1988, 1990). As a result, N availability greatly influences yield expectations for the crop due to altered developmental patterns. The primary objective of this study was to document the delay in sorghum development that might be associated with low soil N fertility. An additional aspect of this study was to examine vegetative development as a possible contributor to the delay in reproductive development associated with low soil N levels. Data were obtained from sorghum plants grown in three field studies conducted in Australia, and in a field study and a controlled environment study in Florida.

MATERIALS AND METHODS

Lawes, Australia. Ontological development was observed for grain sorghum plants (cultivar Dekalb DK55) in an N fertility study at Lawes, Australia (lat. 27° 34' S). Three sowings were performed on 29 Nov. 1989, 28 Aug. 1990, and 3 Oct. 1990. The soil at this site was Lawes clay loam (a deep alluvial, weakly cracking Vertisol, Typic Chromusterts). The preceding crop was a cover crop of oat (*Avena sativa* L.) which was removed in July 1988. The field remained fallow until the sorghum sowings.

Two levels of soil fertility were established in four replicates for each sowing: 0 and 24 g N m^{-2}. In the 24 g N m^{-2} treatment, 12 g N m^{-2} as ammonium nitrate was incorporated into the soil prior to sowing and then two side-dressings of 6 g N m^{-2} each were applied at ≈ 35 and 70 d after sowing. The crops were irrigated as needed to avoid plant water deficits. A full description of the cultural details is given by Muchow and Sinclair (1994).

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The ontogeny of plant development was observed regularly on five adjacent plants in each of the replicate plots. Important to this study, anthesis date was recorded. Anthesis date was defined as the date when anthers were exerted on more than 50% of the panicle.

Green Acres, Florida. Two cultivars of sorghum, 'Asgrow Chaparral' (grain sorghum) and 'Dekalb FS25E' (forage sorghum), were sown at the Green Acres Agronomy Farm near Gainesville, FL (lat. 29° 31' N) on 27 May 1993. Seeds were sown following a rye (*Secale cereale* L.) grain crop using no-tillage techniques. The highly leachable soil at this site was Arredondo fine sand (sandy, siliceous, thermic Grossarenic Paleudults). A split-plot design was used, with three replicated blocks formed using the two cultivars as the whole plots and seven N application amounts (0, 4, 8, 12, 16, 20, and 24 g N m^{-2}) as the split plots. Applications of other nutrients were based on Univ. of Florida Coop. Extension Serv. soil test recommendations. Irrigation was applied through the season to ensure adequate soil moisture.

Plants in each N-application plot were observed every 3 to 4 days for the ontological stages of panicle exersion and anthesis. On each observation date a record was made of the number of plants (out of 24 plants in each plot) that had achieved each of these ontological stages. The date on which 50% of the plants had achieved each of the two ontological stages was estimated by doing a linear interpolation for each replicate plot.

Temperature Gradient Chamber. A Temperature Gradient Chamber (TGC) was constructed at the Univ. of Florida Irrigation Research Park at Gainesville, FL (Sinclair et al., 1995) to allow study of the interactions between soil N availability and temperature. The TGC was formed by erecting a 4.3 × 27.4 m greenhouse directly over the field site used in the study. Inside the TGC, four sections were defined so that a constant temperature difference was maintained along the length of the TGC in four sections: +0, +1.5, +3.0, and +4.5°C. The absolute temperature in the TGC followed ambient conditions although the 'greenhouse effect' at the entrance to the TGC actually raised the base temperature of the +0 plot by 1 to 2°C above ambient conditions (Okada et al., 1995).

Each temperature section was split to give plots of high and low N fertility with dimensions of 2.1 × 5.5 m. Within each plot, sorghum cultivar 'Asgrow Chaparral' was sown directly into the field soil of Arredondo fine sand at this site. Before sowing, 4 g N m^{-2} was incorporated in the low N plots and 21 g N m^{-2} was incorporated in the high N plots. Approximately 32 d after sowing, a second application of N equivalent to the first application was broadcast on the soil surface. The crops were frequently irrigated so that no water deficits developed.

Two seasons of experimentation were done in the TGC, with a sowing on 28 June 1993 (summer) and 12 Nov. 1993 (winter). Fifteen plants in each plot were tagged at the five-leaf stage and subsequently observed weekly. The number of emerged leaves with developed ligules was recorded as well as panicle exersion and anthesis. As before, the date on which 50% of the plants expressed panicle exersion and anthesis was obtained by linear interpolation between observation dates. There were no replicated plots in the TGC, so direct statistical comparisons across temperature treatments were not possible.

RESULTS

Lawes, Australia. The difference in anthesis date was very large between the two N treatments within each of the three sowing dates (Table 1). Plants in the 0 g N m^{-2} treatment had anthesis delayed from 14 to 20 d relative to anthesis in the 24 g N m^{-2} treatment. These data support the original hypothesis that reproductive development is substantially delayed when sorghum is grown under conditions of low soil N availability.

Green Acres, Florida. Anthesis date for the two sorghum cultivars in the Green Acres experiment was also delayed with decreased amounts of applied N (Table 2). The most striking difference was for the forage sorghum, where more than an 18 d delay was observed between the 0 g N m^{-2} treatment and the 16 g N m^{-2} treatment.

The results for grain sorghum, however, showed only a 3.5 d delay in anthesis between the 0 g N m^{-2} and 16 g N m^{-2} N applications. This shorter delay in anthesis for grain sorghum is consistent with the results of Muchow (1990) for the 28 February sowing, where the observed delay was 2.6 d. The length of the period from sowing to anthesis for both the grain sorghum at Green Acres and the 28 February sowing of Muchow (1990) was short. For the high N treatments, the length of period preceding anthesis exersion in both experiments was 62 to 64 d.

Temperature Gradient Chamber. The response of anthesis date to differing N treatments for grain sorghum grown in the summer in the TGC was substantially different from that at Green Acres. Low soil N application as compared to high soil N application resulted in a delay of anthesis by 6 to 7 d for each of the four temperature zones in the TGC (Table 3).

The period from sowing to anthesis was substantially greater in the TGC than under field conditions at Green Acres. At Green Acres, anthesis was achieved for this grain sorghum cultivar under all conditions in 62 to 65.5 d, while in the TGC the time to anthesis ranged from 67.5 to 88.5 d. The major factor that likely accounts for this difference is the elevated temperatures to which the plants grown in the TGC were subjected.

Table 1. Days from sowing to anthesis (± standard error) for sorghum grown under two N regimes at Lawes, Australia.

	Nitrogen application		
Sowing date	0 g N m^{-2}	24 g N m^{-2}	Difference
	d		
29 Nov. 1989	99.8 ± 0.95	85.0 ± 0.00	13.8**
28 Aug. 1990	89.8 ± 1.25	70.0 ± 0.82	19.8**
3 Oct. 1990	87.8 ± 2.93	71.0 ± 0.00	16.8**

**Significant at 0.01 level of probability.

Table 2. Days from sowing to anthesis (± standard error) for sorghum grown under different N treatments at Green Acres, Gainesville, FL.

N treatment	Sowing to panicle exersion for: Grain sorghum	Forage sorghum
(g N m^{-2})	d	
0	65.5 ± 0.47	>113.0
4	63.5 ± 1.40	101.6 ± 2.00
8	64.9 ± 0.82	97.0 ± 1.00
12	63.1 ± 0.14	96.3 ± 1.76
16	62.0 ± 0.54	94.8 ± 0.20
20	63.7 ± 0.44	95.6 ± 0.46
24	62.5 ± 2.27	96.6 ± 2.05

The average daily temperature for the +0°C plot in the TGC was about 29°C. As a result, it is likely that plants grown under elevated temperatures in the TGC were subjected to temperatures above the optimum for sorghum development (Hammer et al., 1989). The negative impact of increasing temperature above an optimum can be seen in the increasing delay to anthesis with increasing temperature in the TGC under both N treatments (Table 3).

In contrast to the development of sorghum in the summer, observations on sorghum grown in the winter in the TGC indicated that the date of anthesis was much less sensitive to the N treatment (Table 3). There was no difference in anthesis date between N treatments for the +0°C plot, and only a 4-d delay with the low N treatment for the +4.5°C plot.

Temperature again had a large effect on the time to anthesis for the winter crop, but its effect was opposite to that for the summer crop. Increasing temperature in the winter experiment greatly accelerated development towards anthesis, as has been reported by others (Gerik and Miller, 1984; Hammer et al., 1989; Muchow and Carberry, 1990). In the winter, the average daily temperature in the TGC (14.5°C for the +0°C plot) was well below the optimum for sorghum development.

In an attempt to resolve the different response to N between the summer and winter crops in the TGC, data on the rate of leaf appearance were examined. For the summer crop, the time to end of leaf development was delayed with increasing temperature similar to the delay observed for anthesis (Fig. 1). The difference in anthesis date between N treatments was also closely related to a slowed rate of leaf appearance under the low N treatment. Therefore, the variation in anthesis date in the TGC for the summer crop was closely associated with variation in the rate of leaf appearance.

For the winter crop, differences between the two N treatments were also associated with differences in the rate of leaf appearance (data not shown). That is, the treatment involving low N application resulted in a slower rate of leaf appearance. This difference in leaf development in response to N treatment was reflected in the date of panicle exersion (Table 4). Panicle exersion was delayed from 6 to 12 d in the low N application treatment as compared to the high N application. The delay in panicle exersion was also observed for the summer crop (Table 4).

Table 3. Date from sowing to anthesis for grain sorghum grown under two N regimes in a Temperature Gradient Chamber (Sinclair et al., 1995).

Temperature increase	Nitrogen application: 8 g N m^{-2}	42 g N m^{-2}	Difference
°C	d		
	Summer		
0	74.9	67.5	7.4
+1.5	77.3	70.7	6.6
+3.0	82.4	75.3	7.1
+4.5	88.5	82.5	6.0
	Winter		
0	90.6	91.5	-0.9
+1.5	—	83.9	—
+3.0	77.5	75.2	2.3
+4.5	80.6	76.7	3.9

DISCUSSION

Major differences in anthesis date were observed in these experiments. This was particularly true for the experiments at Lawes, Australia, where low N applications resulted in delayed anthesis of 14 to 20 d. The results, however, were not consistent across all experiments. It appeared that there may be another major factor influencing expression of delayed anthesis.

Results in the TGC for the two seasons offered an opportunity to examine the variation in plant development to applied soil N levels. A consistent finding in the TGC was that leaf development was slowed by low levels of N. For the summer crop where the temperatures in the TGC were above the optimum for development, a low level of N application was found to delay leaf emergence and panicle exersion. Similarly, for the winter crop, low levels of N application resulted in delayed leaf emergence and panicle exersion (Table 4).

Crops for the two seasons in the TGC, however, differed in their observed delays in anthesis date as a result of low N availability. For the summer crop, the delays in vegetative development associated with low N were paralleled by delays in anthesis date. In contrast, for the winter crop, only small differences between N treatments were observed in anthesis date. Because the number of leaves for the winter crop was unchanged as a result of the N treatment, the length of the period between panicle exersion and anthesis differed with N treatment. Low N resulted in a shorter period between panicle exersion and anthesis. It is speculated that the cool temperatures in the winter inhibited reproductive development at a pace less than that seemingly allowed by the high N treatment. Therefore, the accelerated vegetative development with high N for the winter crop was not expressed, because reproductive development required additional time. The cool winter temperature, in particular, may have been important in setting a specific minimum time for reproductive development.

The hypothesis that there exists a minimum time to reproductive development that can be influenced by temperature also is useful in explaining the other obser-

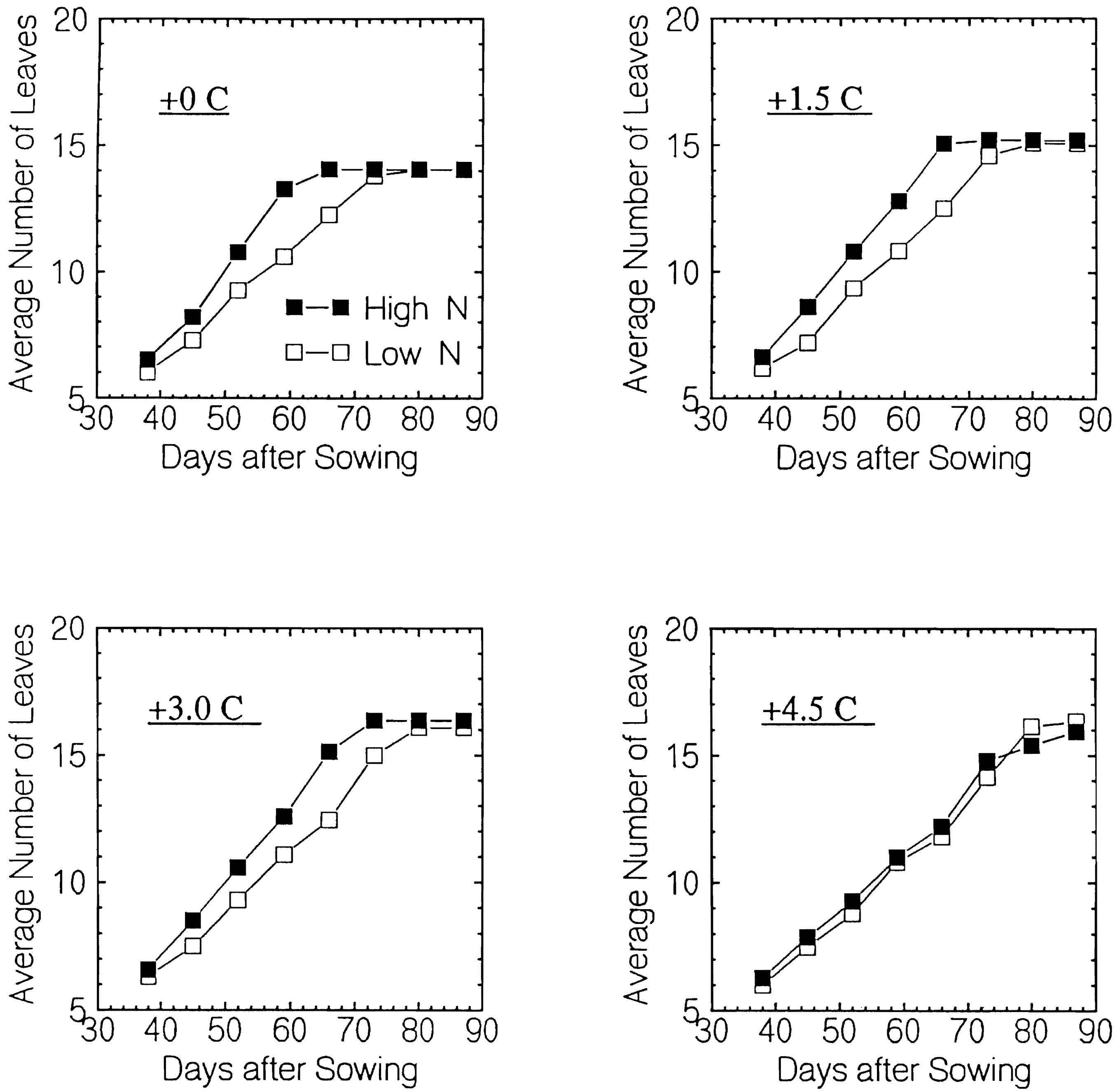

Fig. 1. Leaf appearance for the high and low N availability treatments of the summer sorghum crop for each of the four temperature treatments in the TGC.

vations, where differences in N treatments failed to result in a difference in anthesis date. At Green Acres the temperatures appeared to be near the optimum for the development of grain sorghum, with anthesis occurring in about 63 d for the high N treatments. The optimum temperatures allowed rapid development even under the 0 N treatment, so that the delay in anthesis date was only 2 d.

The other case where there was no response in sorghum anthesis date to N application was for the 28 February sowing of Muchow (1990). Again, in this case, the temperatures were near optimum for plant development and anthesis occurred rapidly at 62 d after sowing. The 0 N treatment is hypothesized to have resulted in a delay in anthesis of only 2 d, because of the rapid development stimulated by optimum temperatures.

Therefore, we conclude that the level of soil N availability can have substantial influence on the development rate of sorghum. Under many circumstances, increasing soil N availability will increase the rate of development and result in an earlier anthesis date. However, temperature clearly has an important influence on development rate and, under some temperature regimes, the N influence may not be expressed.

Table 4. Date from sowing to panicle exersion for grain sorghum grown under two N regimes in a Temperature Gradient Chamber (Sinclair et al., 1995).

Temperature increase	Nitrogen application 8 g N m⁻²	42 g N m⁻²	Difference
°C		d	
		Summer	
0	71.9	64.0	7.9
+1.5	75.3	67.7	7.6
+3.0	78.7	71.0	7.7
+4.5	83.1	77.7	5.4
		Winter	
0	86.2	77.5	8.7
+1.5	—	74.4	—
+3.0	68.1	62.4	5.7
+4.5	75.5	63.5	12.0

The possibility that low soil N fertility may result in delayed development has important practical implications. Certainly, in those environments prone to late season cold and freezing temperatures or to terminal droughts, lengthening of the growing season might put the crop in jeopardy. On the other hand, extension of the season for crops grown under low fertility would allow more time for the crop to accumulate biomass and to produce grain. Assuming no other stresses, lengthening of the pre-anthesis growing season by slowed plant development would help to compensate for some of the negative effects of low N on leaf area development and CO_2 assimilation rates. Therefore, under subsistence conditions, the trait of slowed development rate under low soil N availability which is observed for sorghum may be desirable.

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Reaction of Suerte *Paspalum atratum* to Herbicides

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ABSTRACT

Seedlings of 'Suerte' *Paspalum atratum*, a new pasture grass, were evaluated in 1994 at Ona, FL for reaction to herbicides. Seedling density was 0.0 plants/ft^2 (or /m^2) 70 d after preemergence treatment with clomozone, fluometuron, and imazethapyr vs. 4.0/ft^2 (43/m^2) for no herbicide. Preemergence diuron, metribuzin, trifluralin, and norflurazon also gave substantially lower densities than no herbicide. Postemergence (28 d) treatment with 2,4-D and dicamba + 2,4-D reduced Suerte density somewhat (to 2.4/ft^2 or 26/m^2). Density with dicamba alone (avg 3.3/ft^2 or 36/m^2) was not significantly different from that with no herbicide. Spraying 2-yr old Suerte pasture in 1994 with dicamba + 2,4-D, glyphosate, hexazinone, nicosulfuron, metsulfuron-methyl, sulfometuron-methyl, or triclopyr resulted in little injury and no kill. Fluazifop resulted in injury but no kill, while higher rates of glyphosate resulted in injury and an average 53% kill. On 18 Apr. 1995, 2 rates of fluazifop and 4 rates of glyphosate were applied to 2-yr old Suerte pasture at 2 locations. After 70 d, all treatments had lower densities of live plants than with no herbicide, except for glyphosate at the lowest rate. Percentage kill from glyphosate = -1.3 + 18.6X *or 16.6 X*, where X = active ingredient in lb/A *or kg/ha*. On 27 June 1995, the 7 treatments above were applied to pasture, with glyphosate applied both with and without an additional 10 lb/A (11 kg/ha) of $(NH_4)_2SO_4$. Addition of $(NH_4)_2SO_4$ increased efficacy of glyphosate at the lower rates of application. There was no difference between April and June application for percentage dead Suerte plants. Only dicamba is recommended for weed control on Suerte seedlings, but dicamba, hexazinone, metsulfuron-methyl, and triclopyr may be useful for control of specific weeds in established Suerte pasture. Glyphosate at 2 lb/A (2.2 kg/ha) with 10 lb/A (11 kg/ha) $(NH_4)_2SO_4$, or 3 lb/A (3.4 kg/ha) of glyphosate alone, in water containing antagonistic salts, provided about 90% kill of established Suerte.

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Suerte *Paspalum atratum* Swallen was introduced into Florida in 1990 (Kretschmer et al., 1994) and was released as a cultivar by the University of Florida in 1995. It is a perennial bunchgrass adapted to wet, acid soils. Due to its ease of establishment from seed and the relatively high gains of cattle grazing it, Suerte may be widely used in pastures throughout the humid tropics. Because Suerte can produce as much as 250 lb/A (280 kg/ha) of seed (Kalmbacher et al., 1995), it has the potential of becoming a weed. The purpose of this research was to evaluate: (1) herbicides that may be useful in Suerte establishment or may prevent its establishment, and (2) herbicides that will control weeds in established Suerte pasture or kill Suerte where it is not wanted.

METHODS AND MATERIALS

Herbicide formulas, trade names, and formulations used in all experiments are listed in Table 1. Herbicide rates throughout the text are presented on an active ingredient (a.i.) basis. Water used in all spray solutions came from the same source at the Range Cattle Research and Education Center (RC REC), Ona, FL. Water used for June 1995 treatments was tested for pH and Ca and Mg concentrations (Hanlon and Devore, 1989). All spray volumes were 30 gpa (280 L/ha) applied using a CO_2 sprayer equipped with four, 8006 T-Jet nozzles and 50-mesh screens. Pressure at the tank was 42 psi (290 kPa). Plot size was 6' by 20' (1.8 m × 6.1 m).

Effect of Herbicides on Suerte Seedlings

Preemergence herbicides. One experiment was conducted at the RC REC in 1994 on a Pomona fine sand (sandy, siliceous, hyperthermic Ultic Haplaquods) with a surface-soil pH of 5.8. Trifluralin was applied, and disked into the soil immediately on 5 July 1994. Suerte was then drilled at 5 lb/A (5.6 kg/ha) and fertilized with 50-10-50 lb/A (56-11-56 kg/ha) of $N-P_2O_5-K_2O$, respectively. All plots were rolled twice with a packer to firm the seedbed. Clomozone, diuron, fluometuron, imazethapyr, metribuzin, and norflurazon were sprayed after rolling the seedbed (Table 2).

Postemergence herbicides. On 2 Aug. 1994, 28 d postseeding, dicamba, dicamba + 2,4D, and 2,4-D were applied in solutions containing 0.25% (v/v) of Valent X-77 spreader (Table 2). Suerte seedling density was determined in a 0.6' by 8.9' (0.2 m × 1.8 m) quadrat located in the center of each plot at 28, 49 and 70 days after seeding. The same quadrat location was used on each date. Herbicide injury to Suerte seedlings was determined 49 d after seeding. Injury was based on a scale of 0 (no injury) to 10 (no living leaves). Weed cover was estimated at 70 d postseeding.

Effect of Herbicides on Established Suerte

Four experiments were conducted: one in July 1994 and two in April 1995 at the RC REC and at Quail Creek Ranch in Hardee County, FL on a Myakka fine sand (sandy, siliceous, hyperthermic Aeric Haplaquods) with

Table 1. Description of herbicides in terms of their labeled use and their trade, common, and chemical names.

Trade	Common	Chemical (formulation)
Used on field crops		
Accent	nicosulfuron	2-(4,6-Dimethoxypyrimidin-2-ylcarbamoylsulfamoyl)-N,N-dimethylnicotinamide. (75 DF).
Command	clomozone	2-[(2-Chlorophenyl)methyl]-4,4-dimethyl-3-isoxazolidinone. (4L).
Cotoran	fluometuron	1,1-Dimethyl-3-(α,α,α-trifluoro-m-tolyl)urea. (4 L).
Fusilade	fluazifop-P-butyl	Butyl(R)-2-[4-[[5-trifluoromethyl)-2-pyridinyl]oxy]phenoxy] propanoate. (1 L).
Pursuit	imazethapyr	(±)-2-[4,5-Dihydro-4-methyl-4-(methylethyl)-5-oxo-lH-imidazol-2-yl]-5-ethyl-3-pyridinecarboxylic acid. (2 L).
Sencor	metribuzin	4-Amino-6-(1,1-dimethylethyl)-3-(methylthio)-1,2,4-triazin-5(4H)-one. (5 DF).
Zorial	norflurazon	4-Chloro-5-methylamino-2-(α,α,α-trifluoro-m-tolyl)pyridazin-3(2H)-one. (80 DF).
Used on citrus		
Karmex	diuron	N'-(3,4-Dichlorophenyl)-N,N-dimethylurea. (80 WP).
Treflan	trifluralin	α,α,α-Trifluoro-2,6-dinitro-N,N-dipropyl-p-toluidine. (4L).
Used on pasture		
Ally	metsulfuron-methyl	Dimethylamine salt of methyl 2[[[[(4-methoxy-6-methyl-1,3,5-triazin-2-yl)carbonyl]amino] sulfonyl]benzoate. (60 DF).
Banvel	dicamba	3,6-Dichloro-2-methoxybenzoic acid. (4 L).
Remedy	triclopyr	(3,5,6-Trichloro-2-pyridinyloxy)acetic acid. (4 L).
Velpar	hexazinone	3-Cyclohexyl-6-(dimethylamino)-1-methyl-1,3,5-triazine-2,4(1H,3H)-dione. (2 L).
Weedmaster		1.0 lb dicamba + 2.87 lb 2,4-D/gallon (0.12 + 0.34 kg/L).
Weedar 64	2,4-D	2,4-Dichlorophenoxyacetic acid (4 L amine).
Nonselective/noncropland		
Oust	sulfometuron-methyl	Methyl 2[[[[(4,6-dimethyl-2-pyrimidinyl)amino]carbonyl]amino] sulfonyl]benzoate. (75 DF).
Round-up	glyphosate	Isopropylamine salt of N-(phosphono-methyl)glycine. (4 L).

Table 2. Effect of various herbicides on establishment of Suerte: Seedling density, seedling injury and weed cover. Range Cattle REC, 1994.

Herbicide[†]	Rate[‡]	Application[§]	Seedling density, days postseeding: 28	49	70	Suerte[¶] injury	Weed cover[#] %
	lb/A(kg/ha)		no./ft² (/m²)				
Check	0(0)	0	4.3(46)	3.9(42)	4.0(43)	0	71
Clomozone	1.0(1.1)	pp	0(0)*	0(0)*	0(0)*	10.0*	63
Diuron	2.0(2.2)	pp	0.8(9)*	0.8(9)*	0.7(8)*	5.5*	4*
Fluometuron	1.5(1.7)	pp	0(0)*	0(0)*	0(0)*	10.0*	0*
Imazethapyr	0.063(0.071)	pp	0(0)*	0(0)*	0(0)*	10.0*	15*
Metribuzin	0.5(0.6)	pp	1.0(11)*	0.7(7)*	0.7(7)*	3.5	3*
Norflurazon	1.5(1.7)	pp	2.0(21)*	1.5(16)*	1.5(16)*	1.0	10*
Trifluralin	0.5(0.6)	ppi	1.7(18)*	1.2(13)*	1.2(13)*	1.0	80
Metsulfuron-methyl	0.5(0.6)	28d	4.5(48)	3.5(37)	3.5(37)	1.3	35*
Metsulfuron-methyl	1.0(1.1)	28d	4.8(51)	3.2(34)	3.1(33)	2.5	11*
2,4-D (amine)	1.0(1.1)	28d	4.7(50)	3.3(35)	2.9(31)	4.0	14*
2,4-D	2.0(2.2)	28d	4.3(46)	1.6(17)*	1.4(15)*	7.5*	6*
Weedmaster	0.19 + 0.54 (0.21 + 0.60)	28d	4.3(46)	3.8(41)	3.4(37)	5.3*	16*
Weedmaster	0.38 + 1.1 (0.43 + 1.2)	28d	4.7(51)	3.1(33)	1.9(20)*	7.8*	6*

†Banvel is the trade name for dicamba; Command = clomozone; Cotoran = fluometuron; Karmex = diuron; Pursuit = imazethapyr; Sencor = metribuzin; Treflan = trifluralin; Zorial = norflurazon; 2-4,-D = amine; Weedmaster = 1.0 lb dicamba + 2.87 lb 2,4-D/gallon (0.12 kg/L + 0.34 kg/L). Spray volume was 30 gpa (280 L/ha) with 0.25% (v/v) X-77 (Valent) spreader in a 28-d postseeding application.
‡Active ingredient
§pp = preplant; ppi = preplant incorporated; 28d = applied 28 d postseeding. Suerte was planted at 5 lb/A (5.6 kg/ha) on 5 July 1994.
¶Rating (based on living plants) on a scale 0 (no injury) to 10 (total kill) at 49 d postseeding.
#Weeds were *Cyprus* spp. and broadleaf weeds at 70 d postseeding.
*Treatments different from check ($P < 0.05$, Dunnett's test).

a surface-soil pH = 5.5. The fourth experiment was conducted in June 1995 at Quail Creek Ranch.

Quail Creek Ranch 1994. Dicamba + 2,4-D, fluazifop, glyphosate, hexazinone, metsulfuron-methyl, nicosulfuron, sulfometuron-methyl, and triclopyr were applied on 1 July 1994 to 24-inch (60-cm) tall Suerte, which had been seeded in June 1993 (Table 3). The experiment was in a 14-acre (5.7-ha) unit of a 40-acre (16-ha) pasture that had been fertilized with 60 lb/A (67 kg/ha) of N in March 1994 and 50-10-50 lb/A (56-11-56 kg/ha) of N-P_2O_5-K_2O, respectively, in June 1994. The pasture was rotationally grazed (2 heifers/A, or 5/ha) three times (each 10 to 14 d) between May and August 1994. Herbicide treatments were evaluated 80 d after application on 19 Sep. 1994 for injury and percentage of plants killed. A line was stretched across the diagonal of each plot, and any Suerte plant whose crown was under the line was classified as alive (at least one live leaf) or dead. Injury from herbicides was rated on a scale of 0 (none)to 10 (dead).

Range Cattle REC and Quail Creek, April 1995. On April 18, fluazifop and glyphosate were applied at the RC REC to Suerte plots seeded at 5 lb/A (5.6 kg/ha) on 5 July 1994 (Table 4). Soil was a Pomona fine sand fertilized with 50-10-50 lb/A (56-11-56 kg/ha) of N-P_2O_5-K_2O, respectively, on 5 July 1994 and with 50 lb/A (56 kg/ha) of N on 24 Feb. 1995. The same treatments were applied at Quail Creek Ranch to ungrazed plots in the pasture adjacent to the 1994 site. The pasture had been fertilized with 100-40-40 lb/A (111-45-45 kg/ha) of N-P_2O_5-K_2O, respectively, on 21 Mar. 1995. Suerte plants in a 1.6' by 6.5' (0.5 m × 2.0 m) quadrat were classified as dead or alive and were rated for herbicide injury on 27 June (70 d posttreatment).

Quail Creek Ranch, June 1995. A third adjacent site was selected and sprayed on June 27 using the six treatments applied on April 18 plus four additional glyphosate treatments each with 10 lb/A (11 kg/ha) of diammonium sulfate (spray grade) in the herbicide solution (30 gal/A or 280 L/ha) (Table 5). The untreated check received water containing diammonium sulfate alone. In addition to the fertilizer applied on March 21, 50-10-50 lb/A (56-11-56 kg/ha) was applied on June 9. The pasture had been grazed in May and June by 50 cows and their 49 calves. Treatment effects were evaluated at 70 d posttreatment on September 5 as described above for the April 18 application.

Experimental Design and Analysis

Data were analyzed by analysis of variance (SAS Institute, 1985). Each experiment was designed as a randomized complete block with four blocks. For the 1994 Suerte seedling study at the RC REC, analysis of variance included repeated measures to compare 28, 49, and 70 d density measurements. Locations (18 Apr. 1995 at the RC REC vs. 18 April at Quail Creek Ranch) and dates of application at Quail Creek Ranch (18 April vs. 27 June 1995) were compared as split plots. Dunnett's test ($P < 0.05$) was used to compare the untreated check to all other treatments. Contrasts were used to compare respective rates of glyphosate with or without diammo-

Table 3. Effect of various herbicides 80 d after their application to 24-in. (61-cm) tall, 1-yr old, ungrazed 'Suerte'. Quail Creek Ranch. 1994.

Herbicide[1]	Rate[2]	Suerte	
		Kill	Injury rating[3]
	lb/A(kg/ha)	%	
Check	0(0)	0	0
Dicamba + 2,4-D	0.25+0.7(0.28+0.8)	0	0
Dicamba + 2,4-D	0.50+1.4(0.56+1.6)	0	0.8
Fluazifop	0.25(0.28)	0	5.8*
Fluazifop	0.50(0.56)	0	7.3*
Glyphosate	1.00(1.12)	0	1.0
Glyphosate	2.00(2.24)	0	1.8
Glyphosate	3.00(3.36)	52*	9.3*
Glyphosate	4.00(4.48)	54*	9.8*
Hexazinone	0.50(0.56)	0	1.5
Hexazinone	1.00(1.12)	0	2.0
Metsulfuron-methyl	0.0125(0.014)	0	0
Metsulfuron-methyl	0.0188(0.021)	0	0
Nicosulfuron	0.0234(0.026)	0	0
Nicosulfuron	0.0468(0.052)	0	0.8
Sulfometuron-methyl	0.188(0.211)	0	5.8*
Sulfometuron-methyl	0.281(0.315)	0	7.3*
Triclopyr	0.50(0.56)	0	0.3
Triclopyr	1.00(1.12)	0	0.3

[1]Accent is the trade name for nicosulfuron; Ally = metsulfuron-methyl; Fusilade = fluazifop; Oust = sulfometuron methyl; Remedy = triclopyr; Glyphosate = glyphosate; Velpar = hexazinone; Weedmaster = 1.0 lb dicamba + 2.87 lb 2,4-D/gallon (0.12 kg/L + 0.34 kg/L). Spray volume was 30 gpa (280 L/ha) with 0.25% v/v of X-77 (Valent) spreader. Herbicides applied on 1 July 1994 with ratings on 19 Sep. 1994.
[2]Active ingredient.
[3]Ratings based on a scale of 0 (no injury) to 10 (no living leaves).
*Treatments different from the check ($P < 0.05$, Dunnett's test).

nium sulfate. Regression analysis was used to examine the nature of the response of glyphosate over its levels.

RESULTS AND DISCUSSION

Effects of Herbicides on Suerte Seedlings

Preemergence herbicides. At 28 d after seeding and herbicide application, Suerte seedling density was lower in plots treated with clomozone, diuron, fluometuron, imazethapyr, metribuzin, norflurazon, and trifluralin compared to the untreated check (Table 2). Clomozone, fluometuron, and imazethapyr either prevented germination or killed all Suerte seedlings within days of emergence. Some seedlings escaped the initial effects of diuron, metribuzin, norflurazon, and trifluralin, though density in these plots remained lower than for the check. Except for diuron, injury of surviving seedlings in these treatments was not different from seedling injury in the check. None of the preemergence herbicides could be used as an aid to establishing Suerte, because of outright death or seedling injury. At 70 d posttreatment, broadleaf weed and sedge cover in plots treated with clomozone and trifluralin was not different from that for the check. Weed cover in all other treatments was less than that for the check.

Postemergence herbicides. Conditions for establishment were very good after seeding, resulting in rapid Suerte germination and emergence. Suerte seedlings were 3- to 6- inches (7.6- to 15-cm) tall with 2 to 3 tillers, each with 3 to 4 leaves, when herbicides were applied at 28 d postseeding.

There was a treatment × date of evaluation interaction ($P = 0.001$) resulting in part from effects of postemergence herbicides. At 49 d postseeding (21 d after herbicide application), there were fewer Suerte seedlings in plots treated with 2.0 lb/A (2.2 kg/ha) of 2,4-D compared to the check (Table 2). At 70 d postseeding (42 d after herbicide application), there were fewer seedlings in plots treated with 2,4-D at 2.0 lb/A (2.2 kg/ha) compared to plots treated with 0.38 lb/A dicamba + 1.1 lb/A (0.43 + 1.2 kg/ha) of 2,4-D. There was noticeable Suerte injury at both dates as a result of 1 lb/A (1.1 kg/ha) of 2,4-D alone, but plant response was not significantly different from that for the check. When combined with 0.19 lb/A (0.21 kg/ha) of dicamba, 0.54 lb/A (0.60 kg/ha) of 2,4-D resulted in greater seedling death and injury compared to the check. Weed cover was reduced by all postemergence herbicides. Metsulfuron-methyl was the only herbicide that could be recommended for establishing Suerte but, at 1 lb/A (1.1 kg/ha), metsulfuron-methyl resulted in some seedling death and in injury to surviving seedlings.

Effect of Herbicides on Established Suerte

Quail Creek Ranch, July 1994. Established Suerte seems to be very resistant to herbicides. Only glyphosate at 3 and 4 lb/A (3.4 and 4.5 kg/ha) resulted in any kill on established Suerte (Table 3). Lack of effective herbicide activity was probably not the result of rain washing herbicides off the leaves, because there was no rainfall in a 30 h period after herbicide application on July 1.

Table 4. Effect of fluazifop and glyphosate on density of live, 2-yr old Suerte plants, percentage dead plants, and herbicide injury rating. Herbicides were applied on 18 Apr. 1995 at the Range Cattle REC and Quail Creek Ranch and evaluation was made 70 d posttreatment, on June 27.

Treatment[1]	Rate[2] lb/A(kg/ha)	Live no/ft²(/m²)	Percentage dead Plants		Injury[3]	
			RC REC	Quail Creek	RC REC	Quail Creek
Check	0(0)	1.6(17)	0	0	0	0
Fluazifop	0.25(0.28)	1.3(14)	11	32	8.6*	7.8*
Fluazifop	0.50(0.56)	0.8(9)*	6	87*	9.3*	9.5*
Glyphosate	1.0(1.1)	1.6(17)	6	17	3.0*	6.9*
Glyphosate	2.0(2.2)	1.3(14)	10	43	6.5*	8.6*
Glyphosate	3.0(3.4)	1.3(14)	7	59*	8.1*	9.5*
Glyphosate	4.0(4.5)	0.6(7)*	35*	100*	8.9	10.0*

[1]Fluazifop is the common name for Fusilade and glyphosate is Round-up. Spray volume was 30 gpa (280 L/ha) with 25% v/v of X-77 (Valent) spreader.
[2]Active ingredient.
[3]Ratings based on a 0 (no injury) to 10 (no living leaves) scale.
*Different from the check ($P < 0.05$, Dunnett's test).

About 0.35 in. (9 mm) of rain was measured at the site on the afternoon of July 2. Suerte was not grazed until 4 weeks after herbicide application. Perhaps the lack of control was due to the maturity and mass of Suerte at the time of treatment. As will be shown later, lack of control also may be due to presence of antagonistic salts in the spray water.

There was considerable injury to Suerte from fluazifop and sulfometuron-methyl, particularly at their high rates (Table 3). Hexazinone, which is useful for smutgrass (*Sporobolus indicus*) control in pasture, resulted in a Suerte injury rating = 2. While injury was not severe, such a rating appeared to reduce forage yield and could affect palatability. Of the commonly used pasture herbicides, triclopyr and 0.50 lb/A of dicamba + 1.4 lb/A of 2,4-D (0.56 + 1.6 kg/ha) resulted in slight injury. Observation following a May application of 0.25 lb/A of dicamba + 0.72 lb/A of 2,4-D (0.28 + 0.81 kg/ha) to rapidly growing, young Suerte resulted in modest leaf damage during an earlier test.

Range Cattle REC and Quail Creek, April 1995. Average plant height on April 18 was 9 in. (23 cm) at the RC REC and 14.5 in. (36 cm) at Quail Creek Ranch. Suerte density on April 18 was greater at the RC REC (2.1/ft² or 20/m²) compared to Quail Creek Ranch (1.1/ft² or 10/m²). No rain was received within 72 h of herbicide application.

There was a difference ($P = 0.001$) in density of live Suerte plants due to location ($P = 0.001$) and treatment ($P = 0.001$), with no interaction. Density of live Suerte plants on June 27 averaged 1.9 and 0.7 plants/ft² (18 and 6.5 /m²) at the RC REC and Quail Creek Ranch, respectively. Treatment with fluazifop at 0.5 lb/A (0.6 kg/ha) and glyphosate at 4 lb/A (4.5 kg/ha) resulted in fewer live Suerte plants than for the check (Table 4).

There was an interaction ($P = 0.008$) for percentage of dead plants. At the RC REC, only glyphosate at 4 lb/A (4.5 kg/ha) resulted in more dead plants than for the check (Table 4). At Quail Creek Ranch, there were more dead plants in the fluazifop at 0.5 lb/A (0.6 kg/ha) and in the glyphosate at 3 and 4 lb/A (3.4 and 4.5 kg/ha) treatments compared to the check. Increasing rate of glyphosate linearly increased percentage of dead plants at Quail Creek: % = -4.7 + 24.2X *or 21.6X* (r^2 = 0.60), where X = lb/A *or kg/ha* of glyphosate.

Location and treatment interacted ($P = 0.003$) for Suerte injury rating (Table 4). Injury resulting from fluazifop was similar at both locations, but injury from glyphosate was greater at Quail Creek (rating = 2.5 + 2.3X *or 2.1X* [r^2 = 0.72]) compared to the RC REC (rating = 0.7 + 2.3X *or 2.1X* [r^2 = 0.85]). It is not known why this interaction occurred. Locations were sprayed within hours of each other and there was no rain following treatment. Water was from the same source, although containers may have been filled on different dates.

There were many plants that volunteered in plots at Quail Creek, where Suerte had gone to seed in October 1994. Seedling density increased linearly (no./ft² = -0.33 + 1.16X *or 1.04X* [r^2= 0 44], where X = lb/A *or kg/ha* of glyphosate) from 0.3 in the check to 5.2 plants/ft² with 4 lb/A (4.5 kg/ha) of glyphosate. Density averaged 0.56 and 0.3 seedlings/ft² (5.2 and 2.8 /m²) for fluazifop at 0.25 and 0.5 lb/A (0.3 and 0.6 kg/ha), respectively. The density of volunteer seedlings demonstrates the potential of Suerte to become a weed. For complete Suerte eradication, these data suggest that spray solution should contain both a herbicide to kill existing plants

Table 5. Effect of glyphosate with and without diammonium sulfate (DAS) at 10 lb/A (11 kg/ha) on Suerte at Quail Creek Ranch. Herbicide was applied 27 June 1995 and evaluation took place after 70 d, on September 5.

Rate[1]	Density		Dead plants	
	DAS = 0	DAS = 10	DAS = 0	DAS = 10
lb/A(kg/ha)	------- no/ft²(/m²) -------		-------- % --------	
0(0)	1.8(19)	1.8(19)	0	0
1(1.1)	1.9(20)	0.9(10)*(*)	0	50*(*)
2(2.2)	1.1(12)*	0.2(2)*(*)	33*	87*(*)
3(3.4)	0.1(1)*	0.0(0.0)*	91*	98*(*)
4(4.5)	0.0(0.0)*	0.0(0.0)*	100*	100*

[1]Active ingredient.
*Treatments within a column different from the check (0). ($P < 0.05$, Dunnett's test).
(*)Difference ($P < 0.05$) between diammonium sulfate treatments.

and a preemergence herbicide to prevent establishment of Suerte if a supply of seed exists in the soil.

Quail Creek Ranch, June 1995. The percentage of dead Suerte plants increased linearly (% = -13.5 + 29.1X *or 26.0X* [r^2 = 0.85]) over glyphosate rates when no diammonium sulfate was used and increased quadratically (% = -0.2 + 59.9X - 8.77X^2 *or -0.21 + 53.5X - 6.99X^2* [r^2 = 0.84]) when diammonium sulfate was used (Table 5). There were no dead plants with 1 lb/A (1.1 kg/ha) of glyphosate without diammonium sulfate, compared to 50% dead plants at this rate with diammonium sulfate. At 2 lb/A (2.2kg/ha), there were 33 and 87% dead without and with diammonium sulfate, respectively. Diammonium sulfate improved the efficacy of glyphosate at both 1 and 2 lb/A (1.1 and 1.2 kg/ha). At 1 and 2 lb/A (1.1 and 2.2 kg/ha) of glyphosate, live plant density was lower when diammonium sulfate was used compared to no diammonium sulfate at these glyphosate rates.

Diammonium sulfate has been shown to increase the efficacy of glyphosate for fall control of Johnsongrass (*Sorghum halepense* L.) such that control with 0.75 lb/A (0.84 kg/ha) glyphosate was similar to control with 0.38 lb/ha (0.42 kg/ha) glyphosate in the presence of 3.0 lb/A (3.4 kg/ha) of diammonium sulfate (Salisbury et al., 1991). The improved efficacy of glyphosate in the presence of diammonium sulfate is attributed to precipitation of antagonistic calcium salts from water used in the spray solution (Nalewaja and Matysiak, 1993).

Water used in our trial at Quail Creek had a pH = 7.7 and contained 66 and 37 ppm of Ca and Mg, respectively. Hardness of RC REC water ([Ca ppm × 2.5] + [Mg ppm × 4.1]) was 317 on a scale where >170 is considered very hard water. Adding diammonium sulfate at 10 lb/A (11 kg/ha) to this water lowered pH to 6.9. Concentrations of Ca (61 ppm) and Mg (33 ppm) remained about the same after compared to before adding diammonium sulfate, but suspended salts increased from zero to 67 ppm.

Month (April vs. June 1995) of glyphosate application at Quail Creek had no effect on percentage of dead Suerte plants and did not interact with glyphosate rate. Data in Tables 4 and 5 for percentage dead plants (without diammonium sulfate) can be described by: % = -9.0 + 26.7X *or 23.9X* (r^2 = 0.72). Rating of Suerte injury was greater for application in April compared to application in June. This may be due to smaller, more immature leaves in April, which may be more susceptible to glyphosate.

CONCLUSIONS

Dicamba at 0.5 lb/A (0.6 kg/ha) applied 28 d after seedling is the only herbicide recommended for weed control in Suerte seedlings. Clomozone, diuron, fluometuron, imazethapyr, metribuzin, norflurazon, and trifluralin were each effective at preventing germination or in killing Suerte seedlings immediately after emergence. Herbicides containing 2,4-D (amine) injured or killed Suerte seedlings. Established (at least 1-yr old) Suerte is quite resistant to herbicides. Glyphosate at 2 lb/A (2.2 kg/ha) along with 10 lb/A (11 kg/ha) of diammonium sulfate resulted in about 90% control of Suerte with the hard water (66 and 37 ppm Ca and Mg, respectively) used in these experiments. Without diammonium sulfate, 3 lb/A (3.4 kg/ha) of glyphosate was required to provide 90% control.

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Effects of Fall Application Dates and Rates of N on N and IVOMD in Bigalta Limpograss Segments

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ABSTRACT

Many grasses have low crude protein (CP) concentrations in the fall, especially when used for deferred grazing or for hay. Late N fertilization (LNF) two to three weeks before utilization in November or early December has been shown to increase CP concentration to 70 g kg^{-1} or above. With forage CP above this level cattle intake would not be limited. No information is available on the distribution of CP or digestible energy in grasses after LNF. An experiment was designed to determine the effect of initial fall N fertilization (INF) applied on 22 September or on 2 November, and of a LNF applied on 18 December, on the distribution of CP and *in vitro* organic matter digestibility (IVOMD) in five, 25-cm segments of Bigalta limpograss [*Hemarthria altissima* (Poir.) Staph & C. E. Hubb.]. The grass that had received 50 or 150 kg ha^{-1} N rates in September and November also received 0, 50, or 150 kg ha^{-1} of N as LNF. Only small yield differences existed among like segments (R^2 < 0.25), regardless of date, INF, or LNF. Crude protein was twice the concentration in the terminal segment than in any other segment and increased mostly in response to the LNF N-fertilizer rates. Lowest CP in terminal segments (N treatments averaged) was 79 and 100 g kg^{-1} (7.9 and 10.0%) for the September and November dates, respectively. The lowest CP was 13 g kg^{-1}, found in a basal segment. The IVOMD values were all high, ranging from 580 to 626 g kg^{-1} (58.0 to 62.6%) for the September INF date and 598 to 654 for the November INF date. Calculated TDN data reflected the IVOMD data with the TDN:CP ratios being used to evaluate the feeding value of the segments. Except for most November INF-LNF N rates and several N rates for September, only the terminal segments were deemed to have a balanced TDN (energy):CP ratio (values at or below ≈ 7). Unbalanced (CP deficient) lower segments in November and September N-fertilized grass had TDN:CP ratios ranging from 13 to 19 and 20 to 28, respectively.

Late N fertilization (LNF) of fall-deferred, mature, low CP grasses, for grazing or hay, is used as a method of rapidly increasing crude protein concentration. Nitrogen fertilization of stockpiled grass in the late fall, 2 to 3 wk prior to utilization (Kretschmer, 1964), has been successful in increasing N concentration of Pangola digitgrass (*Digitaria eriantha* Steud.) and Coastal bermudagrass [*Cynodon dactylon* (L.) Pers.] (Kretschmer, 1965), Bigalta limpograss [*Hemarthria altissima* (*Poir.*) Staph & C. E. Hubb.] (Kretschmer and Snyder, 1985), and Callide rhodesgrass (*Chloris gayana* Kunth) (Kretschmer and Wilson, 1995). Unpublished data (Kretschmer et al., 1992) show that, although the LNF technique increased CP, very low IVOMD prevented this technique from being effective for Argentine bahiagrass. With the LNF technique, increases in grass CP concentration depend on initial forage CP, quantity of dry matter (DM) present, and rate of LNF N applied. Highly significant models were developed showing the quantity of LNF N necessary to increase the grass CP concentration (Kretschmer and Snyder, 1979a; 1979b; 1985). Intake of LNF Pangola forage by cattle (Chapman and Kretschmer, 1964) and sheep (Minson, 1967) was higher than for non-LNF grass. The intake increase was attributed to an increase in CP concentration, since CP levels of unfertilized grass were below 7%, the level below which intake is restricted (Milford and Minson, 1965). An increase of CP, and thus an increase in intake of LNF grass, would have a positive effect on animal performance. Also, the distribution of CP and IVOMD and the calculated ratio of total digestible nutrients (TDN:CP) within the stockpiled grass can have an influence on total forage utilization, since intake also is influenced by grass energy levels.

The objective of this experiment was to determine the effect of initial fall N fertilization (INF) rates and dates, and of LNF N rates, on the distribution of CP and IVOMD concentrations in five fractions of Bigalta. Also, the effects of these quality constituents on overall quality was estimated.

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MATERIALS AND METHODS

Bigalta samples were obtained from an experiment more fully described by Kretschmer and Snyder (1985). Briefly, grass was fertilized with 50 or 150 kg ha^{-1} of INF on 22 Sep. or on 2 Nov. 1978. These treatments were used to establish a diversity of dry matter (DM) yields and N concentrations prior to a LNF application on 18 December. Rates of LNF fertilization were 0, 50, and 150 kg ha^{-1} of N applied 22 d prior to harvest, which was on 9 Jan. 1979. Thus, the INF-LNF combinations in this experiment were 50-0, 50-50, 50-150, 150-0, 150-50, and 150-150 kg ha^{-1}.

Fresh plant stems were cut at a 10-cm stubble height. The fresh stems were cut into five 25-cm segments beginning from the meristem. The last basal segments cut were not always 25-cm in length. Stem segments (including leaves) were dried at 60°C to determine yield and dry matter concentration (data not presented), and ground to pass through a 1-mm screen for N and IVOMD analysis (Gallaher et al., 1975; Moore and Mott, 1974).

Statistical analysis involved the use of SAS Goodness of Fit models with four separate step-wise analyses (SAS, 1985) to determine R^2 values. Crude protein and IVOMD data are presented using ANOVA procedures.

RESULTS AND DISCUSSION

Yield

Yield of combined or individual segments was not influenced by INF dates nor, more importantly, by LNF rates (data not presented). This is consistent with previous experiments, because little grass growth can occur during the late fall/early winter (due to cool nights) and during the short interval between LNF and grass utilization. Segments for November LNF treatments generally were lighter in weight than for September LNF treatments. For example, average weight for segments 1 (terminal), 2, 3, and 4 were 6.1, 6.2, 6.1, and 5.6 g, respectively, when fertilized in September, and 6.2, 5.9, 5.3, and 4.1 g, respectively, for November-fertilized grass. The step-wise model used to determine the influence of the independent variables date, INF and LNF revealed that R^2 values ranged from 0.05 to 0.23. This showed the small influence of date, INF, and LNF on segment yield.

Crude Protein

Terminal-segment CP concentrations were always at least twice those of subsequent segments (Table 1). This indicates that the LNF moved primarily to the meristematic area. The INF treatments had much less effect than the LNF treatments, as indicated by the calculated R^2 values. Only 31 (September) and 21% (November) of the change in CP concentrations for INF could be accounted for by the statistical model used. For LNF N-fertilizer influences, however, values were 79 to 89 (September) and 58 to 81% (November), respectively, depending on the segment (data not shown). Higher average CP was generally found in November- than in September-fertilized grass. Lowest CP occurred for both dates and all segments with zero LNF grass.

IVOMD

The digestibility of all segments was excellent (Table 2), though a slight decrease in digestibility occurred with distance away from the terminal segment. For IVOMD the calculated R^2 ranged from 23 to 42, 20 to 21, 28 to 49, and 25 to 50% for segment position, INF date, and INF-LNF within dates, respectively. Average segment (terminal to basal) IVOMD for September INF grass was 661, 630, 591, 579, and 575; and for November INF grass was 665, 646, 609, 609 and 622 g kg^{-1}, respectively. There was benefit in delaying INF fertilization until November. These IVOMD concentrations are much higher than those found for Argentine bahiagrass in a different experiment using the same INF-LNF treatments (Kretschmer et al., 1993, unpublished). Concentrations of IVOMD in Argentine bahiagrass were not affected by N fertilization rates and were in the range from slightly below to slightly above 400 g kg^{-1}. For Callide rhodesgrass, IVOMD concentrations were slightly above 500 g kg^{-1} regardless of LNF rate (Kretschmer and Wilson, 1995).

Quality Aspects

Intake is an important aspect of forage utilization because it is influenced by several factors. Generally, the higher the forage intake the better the animal performance. Intake is reduced when CP in forage (DM basis) falls below about 70 g kg^{-1} (7%). Almost a straight-line intake reduction occurs as CP declines below the 70 g kg^{-1} level (Milford and Minson, 1965). Energy [TDN (IVOMD)] also is an important factor in animal performance, since higher-energy forages normally result in higher animal performance. The ratio TDN:CP is an indicator of potential animal performance (Moore et al., 1991). Based upon the calculated TDN:CP ratio, our data were evaluated as they might influence cattle productivity.

Table 1. Effect of initial (INF) and late (LNF) N fertilizer rates at two INF dates on crude protein (CP) concentration in Bigalta limpograss segments harvested on 9 Jan. 1979.

N rate	INF - LNF N rate (kg ha^{-1})						
	50-0[1]	50-50	50-100	150-0	150-50	150-150	$\bar{x}$
Segment[2]	g kg^{-1}						
	22 September INF						
1	39c[4]	84b	106a	49c	81b	114a	79
2	18c	34b	55a	19c	35b	56a	36
3	16c	33b	53a	15c	30b	46ab	32
4	14c	28b	40a	14c	24b	43a	27
5	13c	23bc	31ab	13c	21bc	36a	23
$\bar{x}$	20	40	57	22	38	59	39
	2 November INF						
1	66d	94bc	111ab	89bc	111ab	127a	100
2	27d	39bc	54abc	43bc	59a	66a	48
3	23c	30b	48a	30b	46a	56a	39
4	21c	28c	45b	29c	39bc	61a	37
5	21c	36bc	44ab	28c	28c	50a	35
$\bar{x}$	32	45	50	44	57	72	51

[1]INF-LNF N fertilizer rates, kg ha^{-1}.
[2]1= terminal 25-cm segment, 5 = basal segment.
INF fertilization dates; LNF fertilization was on 18 December.
[4]Values listed with the same letters within rows are not significantly different at the 5% level of probability.

Table 2. Effect of initial (INF) and late (LNF) N fertilizer rates at two INF dates on *in vitro* organic matter (IVOMD) digestibility in Bigalta limpograss segments harvested on 9 Jan. 1979.

	INF-LNF N rate (kg ha⁻¹)						
N rate	50-0[1]	50-50	50-150	150-0	150-50	150-150	x̄
Segment[2]	g kg⁻¹						
				22 September INF			
1	624c[4]	679a	675a	637b	674a	676a	661
2	624bc	624bc	643abc	595c	617bc	668a	630
3	555c	596b	620a	562c	592b	622a	591
4	544c	597a	597a	554bc	584ab	598a	579
5	551c	575ab	597a	571ab	562abc	593a	576
x̄	580	614	626	584	606	575	607
				2 November INF			
1	635c	663bc	683a	635c	695a	677ab	665
2	608d	653abc	671ab	634abcd	682a	669ab	646
3	587b	593b	634a	587b	621b	629a	609
4	571b	591b	635ab	577b	668a	617ab	609
5	590b	618ab	628b	663a	603b	631b	622
x̄	598	624	648	619	654	622	631

[1]INF-LNF N fertilizer rates, kg ha⁻¹.
[2]1 = terminal 25-cm segment; 5 = basal segment.
[3]INF fertilizer dates; LNF fertilizer date was 18 December.
[4]Values listed with the same letters within rows are not significantly different at the 5% level of probability.

Our IVOMD data when converted to TDN (Table 3) confirm the high quality provided by Bigalta, regardless of foliage canopy level (segment). Average TDN ranged from 560 to 616 g kg⁻¹ (56.0 to 61.6%), with a slight advantage to grass fertilized in November rather than in September. Similar between-date trends occurred for the segment data. Terminal TDN was slightly higher than that for other segments, particularly for the September INF. Grass not receiving LNF N (50-0 and 150-0) generally had lower TDN than that receiving the LNF 50 or 150 kg ha⁻¹ N, but these differences were small considering the overall TDN for Bigalta regrowth after 109 d. These TDN data are at variance with larger trends of CP as discussed earlier, where the N concentration increased as N fertilizer rates increased and as fertilization date was delayed; and markedly decreased from the ter-

Table 3. Calculated total digestible nutrients (TDN) from different INF and LNF N fertilizer rates at two INF dates applied to Bigalta limpograss harvested on 9 Jan. 1979.

	INF-LNF N rate (kg ha⁻¹)						
N rate	50-0[1]	50-50	50-150	150-0	150-50	150-150	x̄
Segment[2]	g kg⁻¹						
				22 September			
1	584[4]	609	607	590	607	608	600
2	584	583	592	571	581	604	586
3	552	571	582	556	569	583	578
4	589	572	572	552	566	572	564
5	551	561	572	560	556	570	562
x̄	575	579	585	566	576	587	578
				2 November			
1	589	602	611	589	616	608	603
2	577	597	605	588	610	604	597
3	567	570	588	567	582	586	577
4	560	569	589	562	604	581	578
5	568	581	586	602	574	587	583
x̄	572	584	596	582	597	593	587

[1]INF-LNF N fertilizer rates, kg ha⁻¹.
[2]1 = terminal 25-cm segment; 5 = basal segment.
[3]INF fertilizer dates; LNF fertilizer date was 18 December.
[4]Calculated as follows: (IVOMD) (0.49) = x; x + 32.2 = y; 0.93y = TDN.

Table 4. Total digestible nutrient (TDN):crude protein (CP) ratios produced by INF and LNF N fertilization rates at two INF dates on Bigalta limpograss harvested on 9 Jan. 1979.

N rate	INF-LNF rate (kg ha⁻¹)						
	50-0[†]	50-50	50-150	150-0	150-50	150-150	$\bar{x}$
Segment[‡]	TDN: CP ratio						
	22 September[¶]						
1	15	7	6	12	7	5	9
2	32	17	11	30	17	11	20
3	35	17	11	37	19	13	22
4	42	20	14	39	24	13	25
5	42	24	18	43	26	16	28
$\bar{x}$	33	17	12	32	19	12	21
	2 November[¶]						
1	9	6	6	7	6	5	7
2	21	15	11	14	10	9	13
3	25	19	12	19	13	10	16
4	27	20	13	19	15	10	17
5	27	16	13	22	21	12	19
$\bar{x}$	22	15	11	16	13	11	14

[†]INF-LNF N fertilizer rates, kg ha⁻¹.
[‡]1 = terminal 25 cm; 5 = basal segment.
Calculated by dividing TDN by CP.
[¶]INF fertilizer dates; LNF fertilizer date was 18 December.

minal to the basal segments. The effects of CP deficiency on overall quality are shown more effectively when TDN:CP ratios are calculated. Moore et al. in 1991 and Moore in 1992 found that the TDN:CP ratio is related to relative intake. If the ratio is below about seven generally there is a satisfactory balance between TDN and CP. Above this value there may be an imbalance, caused by CP deficiency, that reduces forage intake. Low ratios and low quality, however, may occur when both CP and TDN are low. Bahiagrass in the fall and winter is an example of when TDN becomes drastically low, regardless of the low TDN:CP ratio, and intake in this instance is limited by low energy.

Our data for TDN:CP ratio show the imbalance of CP and the importance of regrowth time (109 d for 22 September vs. 68 d for 2 November INF), and of the quantity of N applied as LNF (Table 4). For a given average INF-LNF treatment, 2 November grass TDN:CP ratio was always less than for September grass. Only the terminal 25-cm segments for both dates had values close to seven, with 6 of the 12 terminal segments being less than this value. Applying zero LNF N for September or November INF grass, even at 150 kg ha⁻¹ INF, was less beneficial than when LNF 50 or 150 kg ha⁻¹ was applied (compare terminal-segment data of 15 vs. 7 or 6 at 50 kg ha⁻¹ INF; and 12 vs. 7 or 5 at 150 kg ha⁻¹ INF) (Table 4).

The practical significance of the data may have important consequences for grazing or feeding hay, and when protein supplements or ammonification of hay are used. A useful comparison is that between Bigalta and Floralta limpograss, which has lower IVOMD and TDN values than for Bigalta at the same regrowth stage (Christiansen et al., 1988). The TDN:CP ratios may appear better for Floralta because of similar CP concentrations, compared with Bigalta, while the potential animal productivity with Bigalta is much higher (because of higher TDN) if supplemental N can be provided to balance the ratio. Bigalta limpograss canopies of 100 to 125 cm height with fertilization 6 to 10 weeks prior to grazing in late November/December probably would provide forage of excellent quality without CP supplements until the top (most preferred) portion of the canopy had been completely grazed. After this, addition of supplemental protein probably would continue to provide the quality necessary for maximum forage intake; without the protein supplement, our data show that utilization and animal performance would suffer. Ammoniating Bigalta or Floralta hay may be a good substitute for protein supplements.

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Evaluation of Pearl Millet × Elephantgrass Hybrids for use as High Quality Forage for Livestock

Stanley C. Schank*, D. A. Diz, P. J. Hogue, and C. V. Vann

ABSTRACT

Research priorities of the Univ. of Florida's Dairy Advisory Committee include the development of highly digestible forages. Ideally, new releases would combine high nutritive value, adequate perenniality, and high forage yields. New hybrid pearl millet × elephantgrass hexaploids (*Pennisetum glaucum* (L.) R.Br × *Pennisetum purpureum* Schum.) were tested in three variety trials throughout Florida. Breeder lines designated SV-1 (Silage Variety 1), SV-2 (Silage Variety 2), MS-3 (Mass Selection 3), RRPS-3 (Recurrent Restricted Phenotypic Selection Cycle 3), and cv. Mott dwarf elephantgrass were compared. In 1993 and 1994, SV-1 and Mott were tested at all locations; other combinations included RRPS-3 and MS-3 at Gainesville, RRPS-3 at Branford, and MS-3 and SV-2 at Lake Placid. Dry matter yields were not affected (P < 0.05) by genetic material at Gainesville or Branford, and averaged 6.3 and 7.5 Mg ha^{-1}, respectively. At Lake Placid, MS-3 and Mott (averaging 4.1 Mg ha^{-1}) outyielded SV-1 and SV-2 (averaging 2.1 Mg ha^{-1}). Mott and MS-3 were propagated vegetatively, however, while SV-1 and SV-2 were established by direct seeding. There were no differences in IVOMD (P < 0.05) among lines at any location, nor between crude protein (CP) at Gainesville and Branford. Crude protein values at Lake Placid were higher for SV-1 and SV-2 (averaging 202 g kg^{-1}) than for Mott and MS-3 (averaging 125 g kg^{-1}). Overall, the experiments showed that all breeding lines tested had good dry matter yields, and high IVOMD and CP. Further persistence studies will be needed before the lines can be recommended for farms in Florida.

Research priorities set by the Univ. of Florida's Dairy Advisory Committee on 17 Nov. 1992 included the development of highly digestible forages. The same priorities were also needed for the Florida livestock industry. Previous work had shown that lines that had led to several possible new varieties had high *in vitro* organic matter digestibility (IVOMD) and were highly productive, thereby having the potential for widespread use by the livestock industry. Hybrid crosses of pearl millet with elephantgrass have the additional advantage of being seed-propagated and capable of producing high forage yields. Certain lines possess high nutritive value and adequate perenniality if managed properly.

New hybrid pearl millet × elephantgrass hexaploids were tested as potential new varieties. The most widely studied interspecific hybrids in the genus *Pennisetum* are those between pearl millet and elephantgrass (Gonzalez and Hanna, 1984; Jauhar, 1981; Muldoon and Pearson, 1979). Pearl millet is a diploid ($2n = 2x = 14$) and elephantgrass is a tetraploid ($2n = 4x = 28$). F_1 hybrids between the two parents are triploids ($2n = 3x = 21$) and are sexually sterile. However, fertility has been restored by chromosome doubling. The hexaploids created are ($2n = 6x = 42$), and these hybrid hexaploids were the lines tested in this research study. Previous work had shown that the lines that make up the hexaploids have high *in vitro* digestibility, are very productive, and have the potential to provide the nutrients needed by livestock (Schank and Diz, 1991). New hybrid pearl millet × elephantgrass hexaploids may address this need for a seed-propagated, high quality forage (Diz and Schank 1993, 1995; Diz et al. 1994; Schank 1994).

In Florida, we became interested in the hexaploid hybrids and created several lines which are seed-propagated. The objective of this research was to evaluate progress on these seeded hexaploid lines, and to compare their yields, IVOMD, and CP with Mott dwarf elephantgrass.

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Table 1. Yield, IVOMD, and CP of hexaploid breeding lines at three Florida locations (1993-94). Data are means across two harvests and two years[1].

Location	Lines tested	DM yield	IVOMD	CP
		M ha⁻¹	g kg⁻¹	g kg⁻¹
Hague (DRU)[2]	RRPS-3	6.6 A	560 A	109 A
" "	SV-1	6.2 A	562 A	95 A
" "	MS-3	6.0 A	584 A	97 A
" "	Mott	6.5 A	571 A	94 A
Branford, FL	RRPS-3	8.6 A	620 A	117 A
" "	SV-1	7.3 A	580 A	134 A
" "	Mott	6.5 A	590 A	106 A
Lake Placid, FL	MS-3 (vegetative)	4.6 A	610 A	113 B
" "	SV-1 (seeded)	1.9 B	584 A	208 A
" "	SV-2 (seeded)	2.2 B	626 A	195 A
" "	Mott (vegetative)	3.6 AB	635 A	137 B

[1]Means within a column and location not followed by the same letter are different ($P < 0.05$).
[2]DRU = Dairy Research Unit, Univ. of Florida, Gainesville.

MATERIALS AND METHODS

Advanced lines of the hybrid pearl millet × elephantgrass hexaploids were tested at three locations in 1993 and 1994 as potential new varieties. Breeder lines included SV-1 (Silage Variety 1), SV-2 (Silage Variety 2), MS-3 (Mass Selection 3), RRPS-3 (Recurrent Restricted Phenotypic Selection Cycle 3), and cv. Mott dwarf elephantgrass. Test locations included Gainesville, Branford and Lake Placid. At each location a randomized block design was used. At Gainesville three lines, SV-1, MS-3, and RRPS-3, were compared to Mott. At Branford, the comparisons included SV-1, SV-2, MS-3 and Mott. At Lake Placid, SV-1, SV-2, MS-3, and Mott were compared. Mott was included at all locations to serve as a standard. Mott is vegetatively propagated, and the other lines were propagated using hexaploid seeds. Plots were five rows wide, with each row 3 m wide and 10 m long and with the center row harvested for dry matter yield determinations. Alleys were also 3 m wide, and vegetative varieties were placed between seeded varieties whenever possible (e.g., at Lake Placid). Samples of fresh forage were taken from each plot to assess CP and IVOMD.

RESULTS

Table 1 shows dry matter yield (Mg ha⁻¹), *in vitro* organic matter digestibility (g kg⁻¹) and crude protein (g kg⁻¹) data from three Florida locations. Although there were few differences among breeding lines, it is important to realize that all of the lines were semi-dwarfs, and were being compared to the high-quality 'Mott'. Because none of the hexaploids were inferior to Mott in yield, IVOMD, or CP, it can be concluded that they are *all* of high quality. These data corroborate previous data on IVOMD and CP (Schank et al., 1990) of the hexaploid *Pennisetums*. The IVOMD and CP at Gainesville were not different among the breeding lines. At Branford, there were no differences in IVOMD or CP among the three lines tested. At Lake Placid, no differences in IVOMD were obtained, but CP values were higher for SV-1 and SV-2 than for Mott and MS-3. This difference in CP was due to a difference in maturity because of seed versus vegetative propagation methods used in the experiment at Lake Placid. Because of extremely droughty conditions at Lake Placid, the vegetatively propagated plants established more quickly and subsequently gave significantly higher yields. Also, these vegetative plants gave standard CP values, whereas SV-1 and SV-2 had extremely *high* values. The differences shown in Table 1 at the Lake Placid location are likely due to maturity, rather than genotype.

Overall the experiments showed that all breeding lines tested had good dry matter yields, high IVOMD and high CP. Further persistence studies will be needed before the breeding lines can be recommended to livestock producers in Florida.

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A Dwarf Hexaploid *Pennisetum* Polycross and Analysis of Subsequent Progeny

S. C. Schank* and C. W. Deren

ABSTRACT

A seed-propagated variety of pearl millet × elephantgrass [*Pennisetum glaucum* (L.) R. Br. × *Pennisetum purpureum* Schumach.] offers a major change in the manner in which this forage grass is reproduced. Fourteen heterozygous, dwarf genotypes were combined in a polycross during 1992. Progenies from each of the fourteen parental lines were evaluated and heritabilities for specific traits were calculated. A total of 799 plants were measured for their height, leaf length, leaf width, and number of tillers. Heritabilities were calculated using the maximum likelihood program of Harvey and were 0.66 (height), 0.56 (leaf length), 0.30 (leaf width), and 0.96 (tillers). The data indicate that the traits studied are much more heritable than previously believed, and that genetic progress is possible to further improve a seeded variety of pearl millet × elephantgrass.

Breeding work on hexaploid *Pennisetum* has been underway for about 10 years at the University of Florida (Schank et al., 1991; 1993) with the objective of creating a seed-propagated pearl millet × elephantgrass hybrid. Pearl millet, *Pennisetum glaucum* (L.) R.Br. was the female parent, and elephantgrass (napiergrass) *Pennisetum purpurem* Schumach. the male. This paper is a follow-up from research reported by Diz and Schank (1993; 1995). The original cross which gave rise to the hexaploid lines was a hybridization between Tift 23DA pearl millet (a dwarf) and cv. 'Mott' dwarf elephantgrass. The resultant F_1 progeny were sterile triploids (2N = 3x = 21) but, with chromosome doubling, fertility was restored at the hexaploid level (2N = 6x = 42). Subsequent breeding to tall lines has resulted in a wide variation of phenotypes. Previous work (Hanna, 1981) established methods of reproduction in napiergrass and in the triploid and hexaploid hybrids; and characterized biomass production, cytology and phenotypes from embryogenic callus cultures (Rajasekaran et al., 1986). The purpose of this experiment was to study the variation in progeny of fourteen heterozygous, dwarf genotypes after they had been genetically combined in a field polycross and to calculate heritabilities for specific traits. Sexual propagation of elephantgrass using seeded lines will be able to reach fruition with new information on heritability (Schank, 1994).

MATERIALS AND METHODS

Fourteen hexaploid *Pennisetum* lines were clonally propagated and placed in a polycross breeding nursery located at Belle Glade, FL in 1992 (latitude 26.7°N). Each entry was replicated five times in a randomized complete block arrangement. Entries had been "prescreened" for date of flowering, so they would coincide in flowering date and pollination. Since dwarf lines are extremely late in flowering, the Belle Glade location was essential in order to 1) avoid frost which occurs at more northern locations, and 2) obtain seeds that had intercrossed. Mature seed heads from each line were harvested, which gave sufficient seed for a progeny test at Gainesville in 1993. During 1993, 60 plants from each entry were scored for height, leaf length, leaf width, number of tillers and general vigor. Data were compiled and analyzed using the mixed model least squares and maximum likelihood program of W. R. Harvey (Harvey, 1990), which gave heritabilities. Analysis of variance was performed using the general linear model program of SAS (SAS, 1985).

RESULTS AND DISCUSSION

All fourteen genotypes at Belle Glade flowered near the same date (Table 1). Therefore, we assume that the progeny of each genotype are half-sibs, since the hexaploid is protogynous and wind-pollinated. As shown in Table 1, all of the genotypes produced seed. The best-seeded type was P9, and the lowest seed producers were P14 and P17. Weight of 100 seeds varied from 0.09 to 0.18 g. Germination of the seed ranged from 22 to 75%, with a mean seed germination exceeding 50%. A rather high mortality of seedlings was observed at Gainesville following transplanting. This mortality ranged from 6 to 51%, with a mean of 17.9%.

A total of 799 plants were measured for their height, leaf length, leaf width and number of tillers (Table 2). Data were analyzed using model 2 of Harvey's least-squares program. Heritability estimates on this dwarf population were 0.66 ± 0.24 for height, 0.56 ± 0.21 for leaf length, 0.30 ± 0.13 for leaf width, and 0.96 ± 0.13 for number of tillers. In previous work comparable estimates from a tall hexaploid population were 0.47, 0.37, 1.00, and 0.11. The heritability for height in this dwarf population was 20% higher than for another tall population (Diz et al., 1994; 1995). Leaf length was also more heritable in the dwarf population, but this would be expected because length of leaf, and height, are highly correlated. Number of tillers was also more heritable in the dwarf population. These heritabilities from the dwarf population suggest that the traits studied are much more heritable than previously thought.

Data from an analysis of variance are presented in Table 3. An ANOVA was used in order to obtain ranking of the fourteen genotypes. The genotypes differed ($P < 0.01$) in most of the traits measured. The variation among replications was negligible. A leafiness score was calculated by multiplying leaf length × leaf width × number of tillers. Leafiness is a variable trait in a forage. Using the leafiness scores, P15 and P3 were the most leafy

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Table 1. Fecundity of 14 dwarf *Pennisetums* used in a polycross at Belle Glade, FL, 1992[1].

Plant ID	Number of seed heads	Total seed head weight	Wt. of 100 seeds	Germination	No. progeny in Gainesville	No. dead progeny
		---------------- g ----------------		%		
P1	6.0	1.13	0.16	55	90	46
P3	6.4	0.47	0.10	52	102	34
P5	22.2	2.03	0.13	75	117	19
P6	6.6	0.07	0.11	42	90	15
P7	12.4	1.76	0.14	44	120	19
P9	20.0	4.14	0.16	68	120	15
P10	6.8	0.26	0.14	60	120	8
P11	7.8	0.64	0.12	73	122	20
P14	4.4	0.05	0.14	22	50	3
P15	3.8	0.10	0.15	40	93	8
P16	4.0	0.15	0.09	38	93	14
P17	5.0	0.05	0.10	29	32	8
P18	10.8	2.11	0.13	57	124	13
P19	5.0	1.06	0.18	50	122	19

[1]All means are arithmetic.

Table 2. Heritabilities and genetic, phenotypic and environmental correlations of progeny from a fourteen-parent *Pennisetum* polycross analyzed using a mixed model, least-squares and maximum likelihood computer program (Harvey Model 2).

Variables measured in the matrix	Heritability or genetic correlation	Standard errors	Phenotypic correlation	Environmental correlation
Height, Height	0.66	0.24	1.00	1.00
Height, Leaf length	0.78	0.12	0.67	0.51
Height, Leaf width	0.85	0.10	0.66	0.57
Height, No. tillers	-0.77	0.14	0.08	>1.00
Leaf length, Leaf length	0.56	0.21	1.00	1.00
Leaf length, Leaf width	0.51	0.24	0.57	0.64
Leaf length, No. tillers	-0.69	0.17	0.17	>1.00
Leaf width, Leaf width	0.30	0.13	1.00	1.00
Leaf width, No. tillers	-0.66	0.19	0.15	>1.00
No. tillers, No. tillers	0.96	0.31	1.00	1.00

genotypes, and P7 and P10 were the least leafy. Genotype P9 (Table 3) had the greatest leaf length and the largest leaf width but, since the number of tillers was extremely low, the calculated leafiness score was greatly decreased.

Previous work (Gonzales and Hanna, 1984; Gupta and Athwal, 1966) had established the genetic variability in other related species of *Pennisetum*. Sleper et al. (1977) had shown diallel and path coefficient analyses from tall fescue. Quantitatively inherited traits often require additional statistical analysis (Falconer, 1989).

CONCLUSIONS

1. Genetic correlations can be used to aid in the selection of a specific trait. For example, selecting for higher number of tillers should reduce plant height because these traits are inversely related. However, this should have a desirable effect on the forage obtained.
2. Use of both the Harvey and SAS programs on the same data set has clarified the relationships involved, and has shown that the two programs did not give variable results. Despite considerable genetic variation present in this *Pennisetum* population, the heritability values obtained in this study indicate the large potential possible for genetic improvement in the dwarf *Pennisetums*.
3. The inheritance of height in *Pennisetum* appears to be a quantitatively inherited trait. At the current time, we have not been able to isolate the dwarf gene(s), nor produce "true-breeding" dwarf lines. However, the studies of heritability in the seed-propagated dwarf variety of pearl millet × elephantgrass will hasten the release of a new cultivar that is propagated from seed rather than stem cuttings.

Table 3. Means of variables from progeny from the dwarf *Pennisetum* polycross[1].

Plant ID	Agronomic rating	Height	Leaf length	Leaf width	Tiller number	Leafiness LL*LW*TN 1000
		(m)	(cm)	(cm)		
P1	5.0 GF	1.1 EFG	49.2 DE	3.1 DEF	31.4	58 ABCD
P3	6.8 AB	1.0 EFG	58.6 ABC	3.0 F	33.7	65 AB
P5	5.9 CDE	1.3 CD	56.7 BC	3.4 BCDEF	26.5	56 ABCDE
P6	7.4 A	1.3 CD	54.3 CD	3.6 BC	19.2	42 DEF
P7	5.2 EF	1.5 BC	61.6 AB	3.4 BCDEF	14.3	35 E
P9	6.4 BC	1.8 A	64.6 A	4.1 A	16.9	49 BCDEF
P10	5.3 DEF	1.7 AB	53.4 CD	3.6 BC	19.1	40 EF
P11	6.0 CD	1.7 AB	58.2 BC	3.8 AB	23.7	59 ABC
P14	4.6 FGH	0.6 G	44.3 E	3.0 EF	34.2	56 ABCDE
P15	6.7 ABC	1.1 EFG	49.7 DE	3.5 BCDE	37.4	70 A
P16	4.1 H	1.0 EFG	52.3 CD	3.2 CDEF	21.9	44 CDEF
P17	4.6 FGH	0.9 FG	48.6 DE	3.1 CDEF	29.1	50 BCDEF
P18	4.3 GH	0.9 FG	43.8 E	3.3 BCDEF	29.0	50 BCDEF
P19	4.7 FGH	0.9 FG	44.6 E	3.5 BCD	28.4	52 BCDEF
Means	5.6	1.2	53.4	3.5	25.4	52

[1]All means are arithmetic.

ACKNOWLEDGEMENTS

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1995 PROGRAM
SOIL AND CROP SCIENCE SOCIETY OF FLORIDA
and
Florida Nematology Forum

FIFTY FIFTH ANNUAL MEETING

Holiday Inn Sunspree Resort
and Conference Center
Daytona Beach, Florida
20-22 September 1995

SOCIETY OFFICERS

President . . . . D. L. Wright
President-Elect and Program Chairman . . . . J. W. Noling
Secretary-Treasurer . . . . C. D. Stanley
Director . . . . L. E. Sollenberger (1995)
Director . . . . M. J. Williams (1996)
Director . . . . E. A. Hanlon (1997)

1995 PROGRAM SUMMARY

Wednesday, 20 September 1995

Time	Event	Room
10:00	Board of Directors Meeting	
12:00	Registration Begins	
2:00	Symposium - Florida Farming Systems: Water, Soil, Crop and Environmental Management	Ballroom A
4:30	SCSSF Business Meeting	Ballroom A
6:00	Reception	Pool Deck
	Thursday, 21 September 1995	
8:00	Registration Continues	
8:30	Concurrent Paper Sessions	
	Environmental Quality	Neptune A
	Crops	Neptune B
12:00	Soil and Crop Science Society of Florida Luncheon Speaker: Dr. Richard L. Jones, Dean for Research, Univ. of Florida, IFAS	Ballroom C
2:00	Concurrent Paper Sessions	
	Nematology/Plant Pathology	Neptune A
	Crops	Neptune B
	Friday, 22 September 1995	
8:30	Concurrent Paper Sessions	
	Soils	Neptune A
	Soil/Crop	Neptune B

1995 CONCURRENT PAPER SESSIONS
Wednesday, 20 September 1995

Symposium—Florida Farming Systems: Water, Soil, Crop and Environmental Management: Ballroom A - **Dr. Joe W. Noling, Moderator**

How do Growers Deal with Regulatory-Induced Change. Charlie Matthews, Florida Fruit and Vegetable Association, Orlando.

Impact of Crop Management Practices on Soil Nematode Populations. Robert McSorley, Entomology and Nematology Dep., Gainesville.

Nitrogen BMP Program Implementation. Ken Kuhl, Dep. Agriculture and Consumer Services, Tallahassee.

Developing Improved Irrigation and Nutrient Management Practices to Benefit Agriculture and the Environment—A Case Study. Robert Stamps, Central Florida REC, Apopka.

Thursday, 21 September 1995

Environmental Quality: Neptune A—**Dr. Rosa M. L. Muchovej, Presiding**

Environmental Regulations and Property Rights. R. R. Carriker* and J. E. Reynolds, Food and Resource Economics Dep., Gainesville.

Use of Perennial-Peanut-Based Cropping Systems in Dairy Waste Effluent Sprayfields. K. R. Woodard*, E. C. French, D. A. Graetz, G. M. Prine, and H. H. Van Horn, Agronomy, Soil and Water Science, and Dairy and Poultry Science Depts., Gainesville.

+Application of GLEAMS to Estimate Runoff, Erosion, and Nutrient Losses from Phosphatic Clay. D. Gao* and E. A. Hanlon, Soil and Water Science Dep., Gainesville.

+A Decision Support System for Estimating Agricultural Water Use. P. Papajorgji*, F. S. Zazueta, J. N. Xin and C. Moore, Agricultural and Biological Engineering Dep., Gainesville.

Evapotranspiration of Vegetation in Florida: Perpetuated Misconceptions versus Mechanistic Processes. L. H. Allen, Jr.*, T. R. Sinclair, and J. M. Bennett, USDA/ARS and Agronomy Dep., Gainesville.

Development of a Graphical User Interface for Real-Time Irrigation Control in Greenhouses. R. Testezlaf*, F. S. Zazueta, and T. H. Yeager, Agricultural/Biological Engineering and Environmental Horticulture Depts., Gainesville.

+Application of WETLANDS Model to Simulate Groundwater Flow Patterns in a Cypress-Swamp Flatwoods Landscape. A. Fares*, R. S. Mansell, and S. A. Bloom, Soil and Water Science Dep., Gainesville.

+Study Forest Harvesting Effects on Flatwoods Hydrology with a Distributed Simulation Model. G. Sun*, N. B. Comerford, and H. Riekerk, Forestry and Soil and Water Science Depts., Gainesville.

Mineralization Rates of Granular Municipal Biosolids as Influenced by Limestone. R. M. L. Muchovej* and J. E. Rechcigl, SW Florida REC, Immokalee; and Range Cattle REC, Ona.

Crops: Neptune B—**Dr. Jeff J. Mullahey, Presiding**

Influence of Grazing Frequency on Production and Quality of Paspalum and Brachiara Grasses. P. Mislevy*, G. W. Burton, and L. F. Santos, Range Cattle REC, Ona; USDA/ARS, Tifton, GA; and Naterra Nacional De Sementes Coml. E. Imp. LTDA, Ribeirao Preto, Sao Paulo, Brazil.

Grazing Response to Rye Populations Selected for Improved Yield. R. N. Gates*, G. M. Hill, J. W. Johnson, and P. L. Bruckner, USDA/ARS, Tifton, GA; Univ. of Georgia, Tifton, GA; and Montana State Univ., Bozeman, MT.

Evaluation of Pearl Millet × Elephantgrass Hybrids for Use as High Quality Forage for Livestock. S. C. Schank*, D. A. Diz, P. J. Hogue, and C. D. Vann, Agronomy Dep., Gainesville; and Florida Coop. Extension Service, Sebring and Mayo.

Evaluation of *Desmodium heterocarpon* Hybrids for Dry Matter and Seed Yield. K. H. Quesenberry* and D. E. Moon, Agronomy Dep., Gainesville.

Nitrogen Distribution and IVOMD in Bigalta Limpograss. A. E. Kretschmer, Jr.* and G. H. Snyder, Indian River REC, Ft. Pierce; and Everglades REC, Belle Glade.

Incidence and Control of Tropical Soda Apple in a Commercial Beef Cattle Operation. J. J. Mullahey*, S. Coats and K. Willis, SW Florida REC, Immokalee.

+Evaluation of Tropical Soda Apple Growth Parameters in South Florida. R. U. Akanda*, J. J. Mullahey and C. E. Arnold, Southwest Florida REC, Immokalee.

Reaction of Suerte *Paspalum atratum* to Herbicides. R. S. Kalmbacher*, D. L. Colvin and A. E. Kretschmer, Jr., Range Cattle REC, Ona; Agronomy Dep., Gainesville; and Indian River REC, Ft. Pierce.

Nematology/Plant Pathology: Neptune A—**Dr. R. N. Inserra, Presiding**

Potato Cyst Nematodes, A Potential Menace to the Potato Industry of Florida. R. N. Inserra*, R. McSorley and N. Greco, Dep. Agriculture and Consumer Services, Gainesville; and Entomology/Nematology Dep., Gainesville.

Occurrence of the Citrus Nematode in Florida. J. J. Ferguson*, L. W. Duncan and D. E. Norden, Horticultural Sciences and Agronomy Depts., Gainesville; and Citrus REC, Lake Alfred.

+The Effect of Compost as a Soil Amendment on *Phytophthora nicotianae* and the Growth of Young Citrus Trees. T. L. Widmer*, J. H. Graham and D. J. Mitchell, Citrus REC, Lake Alfred; and Plant Pathology Dep., Gainesville.

Management of Phytophthora Root and Crown Rot and Blight of Citrus with Soil Amendments. S. Nemec* and O. Lee, USDA/ARS, Orlando/Ft. Pierce; and Kissimmee, FL.

Occurrences of and Factors Influencing Blue Mold of Tobacco in Florida for Seventy-Five Years (1921-1995). T. Kucharek* and T. Young, Plant Pathology Dep., Gainesville; Ciba-Geigy Corp., Vero Beach; and Florida Coop. Extension Service, Lake City.

A Method to Evaluate Persistence of *Steinernema riobravis* in Microcosms. L. Duncan* and D. Dunn, Citrus REC, Lake Alfred.

Comparative Pathogenicity of *Steinernema riobravis* and *S. capaterisci* to Mole Crickets. G. C. Smart, Jr.*, Entomology and Nematology Dep., Gainesville.

SEM Studies of Entomopathogenic Nematodes (*Heterorhabditis* spp). K. B. Nguyen* and G. C. Smart. Entomology and Nematology Dep., Gainesville.

Florida Nematology Forum Business Meeting

Crops: Neptune B—**Dr. L. Hartwell Allen, Presiding**

Perennial Peanut: A Status Report for Florida, 1995. E. C. French* and G. M. Prine, Agronomy Dep., Gainesville.

+Establishment and Growth of Perennial Peanut and Bahiagrass in Response to Temperature and CO_2. F. B. Fritschi*, K. J. Boote, L. H. Allen, Jr., L. E. Sollenberger and T. R. Sinclair, Agronomy Dep. and USDA/ARS, Gainesville.

Response of Fresh Market Tomatoes to Foliar Biostimulants and N and K Rates on a Sandy Soil. A. A. Csizinszky*, Gulf Coast REC, Bradenton.

Influence of Summer Grass and Legume Crops on Winter Grown Wheat and Lupin. P. Y. Wiatrak*, D. L. Wright, D. W. Reeves and B. Kidd. North Florida REC, Quincy; Auburn Univ., Auburn, AL; and Agric. Univ. Inst. of Soil Cult. and Plant Prod., Mozowiecke, Poland.

Pigeonpea: Promising Grain Crop for Florida. G. M. Prine* and C. S. Gardner, Agronomy Dep., Gainesville.

Delayed Anthesis in Sorghum under Low Nitrogen Availability. T. R. Sinclair*, R. C. Muchow, R. N. Gallaher and A. K. Schreffler, USDA/ARS and Agronomy Dep., Gainesville; and Cunningham Lab, CSIRO, Brisbane, Australia.

A Dwarf Hexaploid *Pennisetum* Polycross and Analysis of Subsequent Progeny. S. C. Schank* and C. W. Deren, Agronomy Dep., Gainesville; and Everglades REC, Belle Glade.

+Effect of Genotype and Culture Medium on Callus Formation and Plant Regeneration in Red Clover. Y. Poerba* and K. H. Quesenberry, Agronomy Dep., Gainesville.

Friday, 22 September 1995

Soils: Neptune A—**Dr. Joe W. Noling, Presiding**

Simulating Irrigation Requirements for Florida Crops. A. G. Smajstrla* and F. S. Zazueta, Agric. & Biol. Engineering Dep., Gainesville.

Irrigation Frequency of Turfgrass in Central Florida. F. S. Zazueta*, A. G. Smajstrla and B. McCarty, Agric. & Biol. Engineering Dep. and Environmental Horticulture Dep., Gainesville.

+A Model of Coupled Water, Heat and Solute Transport for Bedded-Mulched Systems. D. Shinde*, R. S. Mansell and A. G. Hornsby, Soil & Water Science Dep., Gainesville.

+Reliability of Soil Moisture Measurements Using Sensors. J. Xin*, F. S. Zazueta and A. G. Smajstrla, Agric. & Biol. Engineering Dep., Gainesville.

Background Levels of Trace Metals in Florida Soils. L. Q. Ma* and I. Tan, Soil & Water Science Dep., Gainesville.

Assessing Si Fertilizer for Plant-Available Si. M. P. Barbosa-Filho*, G. H. Snyder, C. L. Elliott and L. E. Datnoff, Everglades REC, Belle Glade.

Nematode Control and Soil Temperature Responses to Applications of Hotwater. J. W. Noling*, Citrus REC, Lake Alfred.

Soil & Crop: Neptune B—**Dr. Fred M. Rhoads, Presiding**

+Characterization of Tomato Root Distribution in Some Florida Production Beds. J. M. S. Scholberg*, B. L. McNeal and J. H. Nguyen, Soil and Water Science Dep., Gainesville.

A Toposequence of Soils in Northern Belize, Central America. C. L. Coultas*, Y. P. Hsieh and T. J. Post, Florida A & M Univ., Tallahassee.

Saptest Tomato-Petiole Nitrate with N Rates Applied Preplant or Injected. F. M. Rhoades* and S. M. Olsen, North Florida REC, Quincy.

Unlimited Nutritional Stability Regardless of the Soil-Crop-Season. C. M. Geraldson*, Bradenton.

Minimizing Matrix Effects in Plasma Spectroscopy through Nebulizer Selection. J. M. Bartos* and E. A. Hanlon, Soil & Water Science Dep., Gainesville.

+Effect of Root-Knot Nematodes on Red Clover Grown in Microplots. N. M. Call*, R. A. Dunn and K. H. Quesenberry, Agronomy and Entomology/Nematology Depts., Gainesville.

Soil Solarization and Fumigant Alternatives for Strawberry Fruit Production. E. A. Albregts*, J. P. Gilreath and C. K. Chandler, Gulf Coast REC, Dover and Bradenton.

***Presentor +Student Paper**

SOCIETY AFFAIRS

MINUTES

Fifty-Fifth Annual Business Meeting
20 September 1995

DR. D. L. WRIGHT

The meeting was called to order by president D. L. Wright at 1630h in Ballroom A of the Holiday Inn Sunspree Resort and Conference Center, Daytona Beach, FL.

Minutes of the 21 Sep. 1994 business meeting, and the financial report, were presented by C. D. Stanley. A motion to accept the minutes was made, seconded and passed. A motion to accept the financial report was made, seconded and passed as well.

B. L. McNeal presented the editor's report, stating that we're running a bit behind this year, due to unforeseen "spare-time" conflicts for the Editor. Proceedings for last year's meeting should be ready for distribution by mid-November. There will be 20 papers (10 crops, 10 soils) therein, compared to 22 in last year's Proceedings. Members of the Editorial Board have rendered excellent and timely service to the Society once again, and the authors have (in general) demonstrated their ability to follow the Society's prescribed instructions while preparing and submitting their manuscripts. We continue to have some problem with Associate Editor "fit" for papers out of the main stream of the Society's traditional disciplinary mix, particularly in the plant-pest area, but will continue to work on this through subsequent Editorial Board nominations. A. J. Smajstrla and M. J. Williams will rotate off the Editorial Board this year, and should be recognized and commended at the annual luncheon for this important service to the Society over the past three years.

After some discussion on the number of copies of the Proceedings currently received as compared to those needed to satisfy members and subscribers, E. R. Emino moved to reduce the number of copies of the Proceedings to something more realistic (established subsequently at 425 for Volume 54). This motion was seconded and passed.

Discussion ensued on the issue of a homeowner's dilemma with respect to getting a house built and civil engineering soil tests for the foundation. There followed a suggestion to appoint a committee (3 members) to investigate the process involved and report to the Board of Directors at the January meeting to see if any action should be taken. It was recommended that R. B. Brown chair the committee, if willing.

J. E. Rechcigl presented the Nominating Committee report. R. S. Mansell was nominated as President-elect and Program Chair for the 1996 annual meeting, and S. C. Schank as a member of the Board of Directors. There was a motion to close nominations, which was accepted and passed, and a motion to approve the nominations, which was also seconded and passed.

D. L. Wright opened discussion with the membership concerning the Board of Directors' deliberations on the Certified Crop Advisor workshop, and associated CEU's. N. Usherwood proposed that SCSSF be listed as co-sponsor of the training program. This was moved, seconded, and passed. C. D. Stanley stated that, if we proceed with these activities, the first call for papers should be moved up considerably (by 2 or 3 months) to facilitate promotion.

E. R. Emino questioned the status of the Society mission statement. Response from D. L. Wright was that it is still in progress.

J. W. Noling reported on investigation into the possibility of a joint meeting with another organization (e.g., FSHS) to improve attendance. The current climate for a joint meeting with FSHS is not very favorable. Dr. Noling will continue to investigate other possibilities.

C. G. Chambliss moved to adjourn. The motion was seconded and passed.

Respectfully submitted,
Craig D. Stanley
Secretary - Treasurer

MINUTES
Board of Directors Meeting
20 September 1995

The meeting was called to order by President D. L Wright at 1005h in the Holiday Inn Sunspree Resort and Convention Center, in Daytona Beach, FL. Members present included D. L. Wright, C. D. Stanley, J. W. Noling, M. J. Williams, L. E. Sollenberger, E. E. Albregts, and E. A. Hanlon. Minutes of the 11 Jan. 1995 board meeting were distributed by C. D. Stanley. Minutes were approved as presented.

A report on investigating the possibility of a joint meeting with another organization (e.g., FSHS) to improve attendance was presented by J. W. Noling. He reported that the current climate for a joint meeting with FSHS is not very favorable. He will continue to investigate this matter.

J. W. Noling asked that, for next year's meeting, a monetary budget for annual meeting expenses be available as a guideline to help with site selection and costs associated with conducting the meeting. M. J. Williams moved that guidelines be set for meeting expenses associated with the next annual meeting, to be presented at the next board meeting. J. W. Noling seconded the motion, and the motion was passed.

C. D. Stanley presented the financial report. M. J. Williams suggested breaking the money in the C.D. into multiple C.D's spread over time, to take advantage of higher interest rates. Information on C.D. possibilities will be presented at the next board meeting. The financial report was accepted as presented.

C. D. Stanley read B. McNeal's editor's report. Details are given in the 20 Sep. 1995 SCSSF business meeting minutes.

D. L. Wright stated that four CEU's had been approved for this year's Certified Crop Advisors' workshop, although the timing was such that we couldn't promote it adequately. If we are to do this in the future, we need to start the process 1-2 months earlier. Discussion followed on developing future meetings, with CEU's specifically in mind. E. A. Hanlon stated that A. G. Hornsby has indicated that he would take the lead in developing a workshop for the CCA program, and recommended that a workshop fee with dues be included for next year. We would need to talk to the IFAS Dean for Extension and to A. G. Hornsby for additional information. If we proceed with this, we probably will need 2 to 3 months more lead time with respect to the first call for papers. The leader on this project will need to receive feedback on current needs if it is to continue annually, and may need to work as part of a subcommittee reporting back to the Board of Directors. E. A. Hanlon will take the lead in making a presentation at the January Board meeting for approval. D. L. Wright appointed E. A. Hanlon to meet with others (N. Usherwood, A. G. Hornsby, D. L. Anderson) to see if a suitable ongoing program can be worked out.

E. A. Hanlon also stated that, if this approach succeeds, we may need to rethink our editorial process in order to include more practical papers. Some changes may need to be made.

D. L. Wright introduced a letter concerning SCSSF interest in helping with a civil engineering problem that one of the members has encountered. No action was taken on this issue.

E. A. Hanlon moved that we adjourn. The motion was seconded and passed.

Respectfully submitted,
Craig D. Stanley,
Secretary - Treasurer

MINUTES
Board of Directors Meeting
11 January 1995

Meeting was called to order by President D. L. Wright at 1300h. Members present included D. L. Wright, C. D. Stanley, J. W. Noling, M. J. Williams, S. H. West, T. A. Obreza, and B. L. McNeal. Minutes of the annual business meeting and the last Board meeting (21 Sep. 1994) were distributed, and were approved as presented.

Discussion ensued on the possibility of a joint meeting with another organization (e.g., FSHS) to improve attendance. M. J. Williams moved that a committee be organized to act as an inter-organization liaison to investigate the potential of such joint meetings. The motion was seconded by J. W. Noling, and passed. D. L. Wright appointed J. W. Noling and S. H. West to handle this matter.

B. L. McNeal announced a need for Associate Editors for the Soil and Water section (2) and the Crops section (1). Suggested names were D. A. Graetz (2-yr term) and T. A. Obreza (3-yr term) for Soil and Water and C. Hiebsh (3-yr term) for Crops. These names were approved. Discussion followed concerning location of a nematology/plant pathology reviewer as well. J. W. Noling will identify someone for this position.

D. L. Wright discussed CEU's for the Certified Crop Advisor Program if SCSSF decides to participate. A typical guideline is that 50 minutes of presentation is equal to 1 CEU.

M. J. Williams moved that D. L. Wright appoint someone to investigate participation in this program and the awarding of CEU's for attending the SCSSF meeting (are we qualified, and/or what is the normal procedure?). This motion was seconded by S. H. West, and passed.

Program Chair J. W. Noling distributed a list of potential symposium topics. Target date for the meeting was established as 20-22 Sep. 1995. Site selection is currently centered around Daytona Beach, Orlando, and Jacksonville, among others.

C. D. Stanley gave a financial report, which was accepted.

B. L. McNeal moved that the meeting be adjourned. J. W. Noling seconded the motion, and it passed.

Respectfully submitted,
Craig D. Stanley,
Secretary - Treasurer

SOCIETY LUNCHEON
21 September 1995

A Society luncheon was held Thursday, 21 Sep. 1995 at the Holiday Inn Sunspree Resort and Conference Center in Daytona Beach, with President D. L. Wright presiding. The invocation was given by J. W. Noling, and the introduction of guests and dignitaries was carried out by D. L. Wright.

Volume 55 of the Proceedings was dedicated to Dr. Kuell Hinson, and Honorary Lifetime Membership was awarded to Dr. D. F. Rothwell. E. A. Hanlon reviewed the careers and service of these long-time members of the Society. The necrology report was given by D. P. Weingartner, followed by a moment of silence in honor of those who had passed away during the preceding year.

J. W. Noling, President-Elect, introduced the guest speaker, Dr. Richard L. Jones, Dean for Research for the Institute of Food and Agricultural Sciences (IFAS), Gainesville. Dr. Jones gave a thoughtful and informative address on "Sustainability of Florida Agriculture."

The gavel was then passed to J. W. Noling as the new President, by retiring President D. L. Wright. On behalf of the Society Dr. Noling presented Dr. Wright with a plaque and expressed appreciation for Dr. Wright's dedicated service to the Society during his term as President. Dr. Noling then adjourned the luncheon at 1330 hr.

GRADUATE STUDENT
PAPER CONTEST

The eighth annual graduate student paper contest was held as part of the Soil and Crop Science Society of Florida's 55th annual meeting. Twelve well-organized papers were presented by graduate students representing the departments of Agricultural and Biological Engineering, Agronomy, Forestry, Plant Pathology, and Soil and Water Science. Five society members, having combined expertise in the subject matter of the papers, judged the presentations with respect to such categories as organization, presentation, visual aids, and subject comprehension.

Ms. Neysa Call, an M.S. candidate in Agronomy under the supervision of Dr. K. H. Quesenberry, won first place and an award of $125 for a paper entitled, "Effect of Root-Knot Nematodes on Red Clover Grown in Microplots". Neysa is a native of Kentucky, where she received her B.S. degree in agriculture from Western Kentucky University in 1993. She was the winner of the American Society of Agronomy Undergraduate Speech Contest in 1992, and began her studies at the University of Florida in the fall of 1993. She will complete her M.S. program in December, with thesis entitled "Red clover (*Trifolium pratense* L.) and root-knot nematode (*Meloidogyne* spp.) interactions". She is currently pursuing a Ph.D. in Crop Science at North Carolina State University. Neysa is a member of Alpha Zeta, Golden Key National Honor Society, and Phi Kappa Phi Honor Fraternity. Her paper is published in this issue of the Proceedings.

Ms. Neysa Call (left), winner of first place in the graduate student paper contest, with her advisor Dr. Kenneth H. Quesenberry, Agronomy Dep.

Daohua Gao, an M.S. student in Soil and Water Science under the direction of Dr. E. A. Hanlon, won second place and an award of $75 for a paper entitled, "Application of GLEAMS to Estimate Runoff, Erosion, and Nutrient Losses from Phosphatic Clay". Mr. Gao, native to the Peoples' Republic of China, received his B.A. degree from Nanjing Agricultural University, and an M.A. degree from the Chinese Academy of Agricultural Sciences. He worked from 1985 to 1994 with the Soil and Fertilizer Institute of the Chinese Academy of Sciences. He is currently working on a Ph.D. degree at Purdue University. His thesis was entitled "Sediment, nitrogen, and phosphorus in runoff from reclaimed phosphatic clay".

Delip Shinde, a Ph.D. student in Soil & Water Science under the direction of Dr. R. S. Mansell, won third place and an award of $50 for a paper entitled "A Model of Coupled Water, Heat and Solute Transport for Bedded-Mulched Systems". Mr. Shinde is from India, and received his B.S. (in agricultural science) and M.S. (in agronomy) degrees from Jawaharlal Nehru Agricultural University in Sehore, Medhya Pradesh, India, and a second M.S. degree (in agricultural engineering) from the Asian Institute of Technology in Bangkok, Thailand. He was employed from 1988 to 1992 by the Parua-Nale Watershed Management Project with the RAK College of Agriculture, Sehore, India. His dissertation is titled "Coupled flow of heat and water in bedded, plastic-mulched soils". His paper is published in this issue of the Proceedings.

Mr. Delip Shinde (right), winner of third place in the graduate student paper contest, with his advisor Dr. Robert S. Mansell, Soil & Water Science Dep.

NECROLOGY

Mr. Willis H. Chapman (78) died 24 Sep. 1994. Mr. Chapman spent his career at the Univ. of Florida North Florida Station (REC) at Quincy. He was born near Liberty, SC, and attended Clemson and North Carolina State Universities, earning an MS in genetics and plant breeding from NCSU in 1938. After continued work with the small grain and corn breeding programs in North Carolina, Mr. Chapman joined the staff of the North Florida Experiment Station as assistant agronomist in 1942. He was promoted to associate agronomist in 1946, to agronomist in 1953 and appointed Station Head in 1959, a post he held until retirement.

Mr. Chapman's areas of expertise were in breeding, genetics, production, culture, and management of small grains, particularly oat. He and his associates used irradiation to induce mutations for resistance to crown rust in oat from a population of Floriland oat. Floriland oat was the first improved variety of any higher crop derived from neutron-irradiated germplasm. Mr. Chapman made numerous other significant contributions during his career and worked independently or with his colleagues on development of some 25 improved varieties of small grains and other field crops. Germplasm of the varieties and breeding lines from his oat program continue to be used throughout the world.

Mr. Chapman served the Univ. of Florida for 36 years until his retirement in 1978. He was a past president of the Soil and Crop Science Society of Florida. Following retirement, Willis and his wife Hilda moved to Cullowhee, NC and later to Greensboro, NC where he resided at the time of his passing. He is survived by his wife and by a daughter, Rebecca.

Dr. Robert John "Bob" Allen, Jr. (83) died 16 Nov. 1994. Dr. Allen was a pasture agronomist and spent his career at the Univ. of Florida Everglades Station. He retired and was granted emeritus status in 1982 after 32 years of University service. Dr. Allen was born in Melrose, MA and attended the Universities of Massachusetts and Maryland, earning his Ph.D. in agronomy at the University of Maryland in 1951. He served in the U.S. Army from 1942-1946, in north Africa, Italy, France, and Germany. He joined the Everglades Station (REC) in 1950, while completing his degree program at Maryland.

Dr. Allen worked on adaptability, selection, and production of pasture and forage crops for south Florida. His research had significant effect on improved cattle production in the area. In the later years of his career he developed a weather station observatory for south Florida at Belle Glade, and focused on the importance of solar radiation on crop production.

Dr. Allen was active with a number of civic organizations in the Belle Glade area. In addition to the Soil and Crop Science Society of Florida, he was a member of the American Society of Agronomy, Association of Southern Agricultural Workers, Sigma Xi, Phi Kappa Phi and several additional professional organizations. After retirement he spent much of his time with the Shriners, and sponsored 87 children at Shriners Hospital.

Dr. Allen is survived by his wife, Evelyn, of Gainesville, a daughter and son, four grandchildren, and two great grandchildren.

Dr. Ernest L. Spencer (89) died 20 Jan. 1995. He was born during 1906 in Saco, ME, attended Maine and Massachusetts primary and secondary schools, and graduated from Massachusetts Agricultural College. He later received both his M.S. and Ph.D. (the latter in 1932) degrees from Rutgers University. His chief scientific interests were in the areas of plant physiology and soil chemistry, with a research career that spanned a period of almost 40 years.

After 12 years of research at Rutgers University and with the Rockefeller Institute for Medical Research, Dr. Spencer came to the Gulf Coast Experiment Station (REC) in Bradenton, FL during 1943, as a soil chemist. In 1950 he was promoted to Soil Chemist-in-Charge of the Station, a post he held until his retirement from the Florida Agric. Experiment Station system in 1968. A tireless worker, innovative researcher, and gifted administrator, "Ernie" made major contributions to the agricultural industries of Florida, especially in the area of vegetable crops.

Dr. Spencer served as President of the Soil and Crop Science Society of Florida, and was also selected as an Honorary Life Member of the Society. He served for a number of years as secretary of the Florida State Horticultural Society.

Dr. Spencer served both as director and as president of the Boy's Club of Manatee County, and also served as District Chairman for the area's Boy Scouts of America organization. His wife Elsie preceded him in death, as did a brother and two sisters. He is survived by a sister and two nieces.

Dr. Donald Eugene Stokes (64) died 22 Mar. 1995. Dr. Stokes was born in Andalusia, AL in 1931. He received a B.S. in agronomy in 1956, and an M.S. in plant pathology in 1963. In 1956 he joined the Plant Inspection Department of the Florida State Plant Board as a Plant Inspector. Plant nurserymen in the Tampa area were so impressed by his ability that they contributed to a scholarship fund to assist Don with his graduate program. In 1966 he joined the nematology section of the Florida Dep. of Agriculture and Consumer Services. During his employment with the Florida Dep. of Agriculture, he pursued and earned his Ph.D. in nematology, in 1972, at the Univ. of Florida. He was appointed Chief of the Nematology Section in December 1975, and continued in that capacity until his retirement in 1982. Dr. Stokes authored or co-authored 33 nematological publications during his tenure with the Section of Nematology. He was a member of the Society of Nematologists, the Soil and Crop Science Society of Florida, the Organization of Nematologists of Tropical America, and the European Society of Nematologists.

Dr. David H. Hubbell (57) passed away 26 Aug. 1995. Dave, a soil microbiologist, was a faculty member in the Univ. of Florida Soil and Water Science Dep. He also held affiliate professorships in both the Microbiology and Cell Science Depts. and the Center for Latin American Studies. Dr. Hubbell was born during 1937 in Albuquerque, NM and grew up in New Mexico, Arkansas, and Virginia. He attended Virginia Polytechnic Institute and North Carolina State University, obtaining his doctorate in Microbiology from NCSU in 1966. He began his career as interim assistant professor in the laboratory of Dr. M. Alexander at Cornell University. Dr. Hubbell joined the staff of the Univ. of Florida's Soil Science Department in 1969.

Dr. Hubbell's research dealt primarily with the mechanisms of legume root hair infection by *Rhizobium.* His research documented ultrastructural events of cell wall penetration, demonstrated the presence and role of extra-cellular hydrologic enzymes of *Rhizobium* in the infection process, and demonstrated the role of lectins in the pre-infection events of recognition and binding of *Rhizobium trifolii* to clover roots. Dr. Hubbell's applied research led to greater ease of use and effectiveness of granular and pelletized inoculant formulations, and demonstrated the efficacy of gum arabic as an inoculant sticker. He was a respected and enormously popular teacher, and served as a consultant and lecturer in 18 different Latin American and Asian countries. Dr. Hubbell was active in many professional societies and was a Fellow of SSSA. He was a President's Scholar at the Univ. of Florida in 1975-76, and Divisional Lecturer at the American Society for Microbiology's national meeting in 1980. Dr. Hubbell also served on the editorial boards of several national journals, and as chair of SSSA Division S-3.

Dr. Hubbell is survived by his wife, Barbara, and children Janine, Lydia, and David.

RESOLUTION OF SYMPATHY

Now, therefore, be it resolved that this expression of sorrow over these great losses and of sympathy to the immediate families of the deceased be spread upon the records of this Society and that a copy of the same be sent to the closest member of the family of each.

Respectfully submitted,
F. M. Rhoads
E. C. French
D. P. Weingartner, Chair

FINANCIAL REPORT
1 July 1994 through 30 June 1995

ASSETS IN BANK (1 July 1994)		
Checking account—Barnett Bank		$ 7,838.59
Money Market—Sun Bank		11,407.38
Total in bank		**19,245.97**
RECEIPTS		
Dues		3,040.00
Regular	3,040.00	
Sustaining	00.00	
Sale of Proceedings		2,035.00
Page charges, Volume 53		2,880.00
Annual meeting		2,840.00
Banquet	120.00	
Registration	2,720.00	
Interest—Money Market account		300.94
Total receipts		**11,095.94**
DISBURSEMENTS		
Publication of Volume 53		5,586.98
Postage		668.44
Expenses of annual meeting		2,220.67
Programs and supplies	398.65	
Banquet and breaks	1,822.02	
Office supplies		124.26
Miscellaneous		61.25
Total disbursements		**8,661.60**
ASSETS IN BANK (30 June 1995)		
Checking account - Sun Bank		9,971.99
Money Market Account - Barnett Bank		11,708.32
Total in bank		**$21,680.31**

1996 COMMITTEES

(Date in parenthesis indicates year each member rotates off after the annual meeting.)

Audit

D. M. Sylvia, Chair	(1996)
T. A. Obreza	(1997)
J. W. Noling	(1998)

Necrology

E. C. French, Chair	(1996)
F. M. Rhoads	(1997)
G. M. Prine	(1998)

Nominating

K. H. Quesenberry, Chair	(1996)
R. D. Barnett	(1997)
Paul Mislevy	(1998)

Site Selection/Local Arrangements

M. E. Collins, Chair	(1996)
C. G. Chambliss	(1997)
D. J. Pitts	(1998)
C. D. Stanley, Ex Officio	

Dedication of Proceedings and Honorary Lifetime Member Selection

E. A. Hanlon, Chair	(1996)
E. B. Whitty	(1997)
G. C. Smart	(1998)

Membership

Paul Mislevy, Chair	(1996)
R. A. Kinloch	(1996)
L. E. Sollenberger	(1997)
T. D. Hewitt	(1997)
A. K. Alva	(1998)
J. J. Mullahey	(1998)

Graduate Student Paper Contest Committee

Robert McSorley, Chair	(1996)
T. A. Kucharek	(1997)
L. W. Duncan	(1998)

EDITORIAL REPORT

The editorial responsibilities for Volume 55 of the Soil and Crop Science of Florida Proceedings were shared by six associate editors and an editor. The invaluable assistance and cooperation by many individuals in the publication of this volume are recognized and gratefully acknowledged. The editor expresses special thanks and appreciation to Jeff Johnston of E.O. Painter Printing for his patience and assistance with production again this year, ably maintaining a long-standing family tradition.

Respectfully submitted,
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T. A. Obreza
(Associate Editor, Soil & Water)
F. S. Zazueta
(Associate Editor, Soil & Water)
D. L. Anderson
(Associate Editor, Crops)
C. K. Hiebsch
(Associate Editor, Crops)
Robert McSorley
(Associate Editor, Crops)
B. L. McNeal
(Editor)

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1995	D. L. Wright	J. W. Noling	C. D. Stanley	L. E. Sollenberger
1994	E. E. Albregts	D. L. Wright	C. D. Stanley	D. A. Graetz
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1992	G. C. Smart, Jr.	G. H. Snyder	C. G. Chambliss	F. M. Rhoads
1991	R. S. Kalmbacher	G. C. Smart, Jr.	C. G. Chambliss	N. R. Usherwood
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1989	J. B. Sartain	R. D. Barnett	C. G. Chambliss	R. W. Johnson
1988	P. Mislevy	J. B. Sartain	D. D. Baltensperger/C. G. Chambliss	J. W. Prevatt/J. B. Sartain/ B. L. McNeal
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1984	G. M. Prine	J. G. A. Fiskell	G. Kidder	P. Mislevy
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1982	O. C. Ruelke	F. M. Rhoads	G. Kidder	G. M. Prine
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1980	V. W. Carlisle	A. J. Overman	J. B. Sartain	F. M. Rhoads
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1977	K. Hinson	W. L. Pritchett	D. W. Jones	A. J. Overman
1976	H. L. Breland	K. Hinson	D. W. Jones	R. L. Smith
1975	A. E. Kretschmer, Jr.	H. L. Breland	D. W. Jones	A. L. Taylor
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1967	G. B. Killinger	C. M. Geraldson	J. NeSmith	
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1964	D. O. Spinks	V. E. Green, Jr.	R. V. Allison	
1963	H. C. Harris	D. O. Spinks	R. V. Allison	
1962	W. G. Blue	H. C. Harris	R. V. Allison	
1961	W. H. Chapman	W. G. Blue	R. V. Allison	
1960	J. R. Henderson	W. H. Chapman	R. V. Allison	
1959	P. H. Senn	J. R. Henderson	R. V. Allison	
1958	G. D. Thornton	P. H. Senn	R. V. Allison	
1957	D. E. McCloud	G. D. Thornton	R. V. Allison	
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1951	R. A. Carrigan	I. W. Wander	R. V. Allison	
1950	W. T. Forsee, Jr.	R. A. Carrigan	R. V. Allison	
1949	W. T. Forsee, Jr.	R. A. Carrigan	R. V. Allison	
1948	H. A. Bestor	L. H. Rogers	R. V. Allison	
1947	H. A. Bestor	L. H. Rogers	R. V. Allison	
1946	H. Gunter	H. A. Bestor	R. V. Allison	
1945	W. E. Stokes	H. Gunter	R. V. Allison	
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1943	H. I. Mossbarger	G. M. Volk	R. V. Allison	
1942	J. R. Neller	H. I. Mossbarger	R. V. Allison	
1941	F. B. Smith	J. R. Neller	R. V. Allison	
1940	M. Peech	F. B. Smith	R. A. Carrigan	
1939	R. V. Allison	M. Peech	R. A. Carrigan	

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*Prior to 1953, the minutes printed in the Proceedings do not name the Editor, although a publication report is printed and an Editor is mentioned. The minutes imply, but do not explicitly state, that for the first several years there was an Editorial Committee with the Chairman of the Committee serving as Editor.

The Soil Science Society of Florida was formed on 18 April 1939 under the leadership of Drs. R. V. Allison, R. A. Carrigan, F. B. Smith, Michael Peech, and Mr. W. L. Tait. In 1955 the name was changed to the Soil and Crop Science Society of Florida. The Society was incorporated as a non-profit organization of 6 June 1975. The articles of incorporation were published in Volume 35 of the Proceedings, and the By-Laws in Volume 41.

Volumes 31 and 44 of the Proceedings listed the previous officers of the Society. The information listed above draws heavily upon those two volumes and the minutes of the Society published in each volume. I discovered a few errors, especially in the Board of Directors, and all have been corrected to the best of my knowledge.

Grover C. Smart, Jr. President, SCSSF, 1991-92.

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1943	5-A	Nathan Mayo
1943	5-B	Wilmon Newell
1944	6	Herman Gunter
1945	7	Lewis Ralph Jones
1946-47	8	Millard F. Caldweld
1948-49	9	Willis E. Teal, Col. USA
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1952	12	Robert M. Salter
1953	13	J. Hillis Miller
1954	14	Lyman James Briggs
1955	15	Lorenzo A. Richards
1956	16	T. L. Collins & Fla. Water Resource Study Commission
1957	17	Firmin E. Bear
1958	18	Harold Mowry
1959	19	Work & Workers in the Fla. Agr. Ext. Serv. 1939-59
1960	20	Roger W. Bledsoe
1961	21	Doyle Conner
1962	22	R. V. Allison
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1985	44	Theodore (Ted) W. Winsberg
1986	45	Gerald O. Mott
1987	46	J. G. A. Fiskell
1988	47	Francis Aloysius Wood
1989	48	Victor E. Green, Jr.
1990	49	Earl S. Horner
1991	50	Amegda J. Overman
1992	51	William Guard Blue
1993	52	Charles E. Dean
1994	53	Luther C. Hammond
1995	54	Allan J. Norden
1996	55	Kuell Hinson

*In the earlier years, the Proceedings bear a date which coincides with the year of the annual meeting. During the years of World War II, publication was irregular and at least some of the volumes were published after the war. Also, the actual year that a publication is available becomes the "legal" date of a issue, not the year the meeting was held. Thus, volumes 32 and after bear a date one year after the annual meetings.