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Survey of Crop Losses in Response to Phytoparasitic Nematodes in the United States for 1994[1]

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Abstract: Previous reports of crop losses to plant-parasitic nematodes have relied on published results of survey data based on certain commodities, including tobacco, peanuts, cotton, and soybean. Reports on crop-loss assessment by land-grant universities and many commodity groups generally are no longer available, with the exception of the University of Georgia, the Beltwide Cotton Conference, and selected groups concerned with soybean. The Society of Nematologists Extension Committee contacted extension personnel in 49 U.S. states for information on estimated crop losses caused by plant-parasitic nematodes in major crops for the year 1994. Included in this paper are survey results from 35 states on various crops including corn, cotton, soybean, peanut, wheat, rice, sugarcane, sorghum, tobacco, numerous vegetable crops, fruit and nut crops, and golf greens. The data are reported systematically by state and include the estimated loss, hectarage of production, source of information, nematode species or taxon when available, and crop value. The major genera of phytoparasitic nematodes reported to cause crop losses were *Heterodera, Hoplolaimus, Meloidogyne, Pratylenchus, Rotylenchulus,* and *Xiphinema.*

Key words: Alfalfa, *Allium cepa,* almond, *Aphelenchoides besseyi, Apium graveolens,* apple, *Arachis hypogaea,* avocado, banana, *Belonolaimus longicaudatus,* blueberry, Brassicaceae, *Brassica oleracea, Capsicum frutescens, Carica papaya,* carrot, carrot cyst nematode, *Carya illinoensis,* cauliflower, celery, cherry, citrus, *Citrus* spp., citrus nematode, *Coffea arabica,* coffee, *Colocasia esculenta,* Columbia lance nematode, corn, corn cyst nematode, crop loss, dagger nematode, *Daucus carota,* distribution, *Ficus carica,* fig, *Fragaria* × *ananassa, Globodera tabacum, Glycine max, Gossypium hirsutum,* guava, *Helicotylenchus, Heterodera carotae, Heterodera glycines, Heterodera goettingiana, Heterodera schachtii, Heterodera zeae, Hoplolaimus columbus, Hoplolaimus galeatus, Ipomea batatas,* Irish potato, Javanese root-knot nematode, *Juglans* sp., *Lactuca sativa,* lance nematode, lettuce, *Longidorus africanus, Longidorus breviannulatus, Lycopersicon esculentum, Macadamia integrifolia,* macadamia nut, *Malus sylvestris, Medicago sativa, Meloidogyne arenaria, Meloidogyne chitwoodi, Meloidogyne hapla, Meloidogyne incognita, Meloidogyne javanica, Meloidogyne nataliei, Mesocriconema ornata, Mesocriconema xenoplax, Musa paradisiaca,* nectarine, needle nematode, nematode, *Nicotiana tabacum,* northern root-knot nematode, *Olea europa,* olive, papaya, pear, peach, pecan, *Paratrichodorus allius, Paratrichodorus minor,* peanut root-knot nematode, *Persea americana, Persea gramtissima, Pistachia vera,* pistachio, plant disease loss, *Psidium guajava, Pratylenchus brachyurus, Pratylenchus coffeae, Pratylenchus neglectus, Pratylenchus penetrans, Pratylenchus thornei, Pratylenchus vulnus,* prune, *Prunus amygdalus, Prunus avium, Prunus persica, Quinisulcius acutus,* raspberry, reniform nematode, resistance, rice, root-knot nematode, *Rotylenchulus reniformis, Rubus* spp., *Saccarhum officinarum,* soybean cyst nematode, spiral nematode, strawberry, stubby root nematode, sting nematode, stunt nematode, Solanaceae, *Solanum tuberosum,* sorghum, *Sorghum vulgare,* southern root-knot nematode, sugar beet cyst nematode, sugar cane, sweetpotato, taro, tobacco cyst nematode, *Trichodorus allius, Triticum aestivum, Tylenchorhynchus, Tylenchulus semipenetrans, Vaccinium,* walnut, *Zea mays,* wheat, white-tip nematode, *Xiphinema americanum, Xiphinema index, Xiphinema pachtaicum.*

Prior to 1987, only one crop-loss assessment related to phytoparasitic nematodes had been published (Feldmesser, 1971). Crop-loss estimates due to phytoparasitic nematodes for selected crops on a worldwide basis were reported in 1987, and an additional document on U.S. crops and estimated yield losses became available that same year (Sasser and Freckman, 1987; Society of Nematologists Crop Loss Assessment Committee, 1987). World crop losses published by Sasser and Freckman (1987) were based on survey data collected for that purpose. The 1987 U.S. bibliography relied on

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published reports that in most instances also were based on survey information. Although most administrators and nematologists agree that crop-loss assessments are important in order to justify public expenditures for research and education programs in nematology and plant pathology, increasingly the sources of such information are unavailable. For example, the 1987 bibliography relied on the pesticide impact assessment program conducted by the U.S. Department of Agriculture (USDA) in the 1980s (U.S. Department of Agriculture, 1985a, 1985b, 1985c, 1985d, 1985e). Pesticide impact assessment continues, but the form of data collection and publication changes in response to perceived needs of the reporting agency to supply information relevant to particular issues. For example, the proposed ban on methyl bromide and various other pesticides has resulted in economic analysis of alternatives (Pike et al., 1995; United Nations Environmental Programme, 1995; U.S. Environmental Protection Agency, 1993; U.S. Department of Agriculture, 1993). Michigan and North Carolina maintained comprehensive estimates of crop losses in response to disease and (or) nematodes, but these publications have since been discontinued because of funding constraints (Bird and Graney, 1986; Main and Byrne, 1986; Main and Nusser, 1985). The only state still maintaining a comprehensive database on crop losses appears to be Georgia (Bertrand, 1995). Groups working with particular commodities periodically or annually develop estimates, but these efforts on several commodities (notably tobacco and peanuts) have been discontinued (Arnett, 1984; Sturgeon, 1984). Nevertheless, progress has been made in determining damage functions, conducting surveys on the distribution of plant-parasitic nematodes, and developing the methodology for obtaining loss estimates (Duncan and Noling, 1998). References to publications on loss estimates and nematode surveys are included for each commodity, where available.

Pest-specific crop-loss information is needed by government agencies, corporations involved with crop protection and production, as well as university systems for descriptive and predictive purposes (Noling, 1987; Teng, 1985, 1987). Regulatory policy actions, pesticide impact assessments, resource allocation, and program prioritization are frequently contingent upon crop-loss data. On-farm pest management decisions also are formulated within the context of anticipated crop losses and pest control costs (Ferris and Noling, 1987).

Information requirements for crop-loss assessment purposes must include estimates of crop distribution and value, pest distribution and average infestation level, and finally a damage function relating average infestation and crop yield. All these estimates are susceptible to error, and interaction effects among biological components are difficult to analyze (Noling, 1987). The objectives of this paper were to: (i) focus on major U.S. commodities with respect to crop loss and update crop-loss estimates for nematodes on a regional and national basis, (ii) provide a point of reference for future comparisons of changes in the magnitude of estimated losses, and (iii) describe crop loss with respect to current production practices and predict any losses occurring with alternative methods of nematode management.

Materials and Methods

The production and value of specific crops and states presented in this publication were obtained from official state or national agricultural statistics service annual reports (Anonymous, 1995a, 1995b, 1996, 1997). In some instances figures provided to us by states did not match USDA estimates, thus total hectarage and value figures may not agree in tables. The survey document requested information in English measure, and these have been converted to metric. Crop hectarage and value data are rounded off to whole thousands of hectares and whole millions of dollars, unless states had less than 1,000 hectares.

For this report, crop loss is defined as the direct physical reduction in yield and crop value due to a particular pest or group of pests. Accurate assessments of crop loss due to nematodes are not readily available, however, and are difficult to define because specific pest-crop data bases relating nematode infestation with crop yield have not been conducted over time and location for most crops.

Estimates of crop loss provided in this publication are based almost exclusively on survey (Patton, 1982) and inquiry (Israel, 1998) techniques to poll the expert opinions of state university crop production and pest management specialists. Members of the Society of Nematologists extension committee attempted to contact nematologists or plant pathologists in all states for 1994 information only. Repeated efforts were made to contact individuals through phone calls and electronic mail. After much of the survey information was gathered, it was suggested that we determine what percentage of the hectarage of each crop received a particular control method. Attempts to gather this information were largely unsuccessful. Consequently, the responses published in this paper represent crop-loss estimates provided from 35 states and more than 80 experts.

Estimates of crop loss in this publication were predicated on current management practices, including the use of nematicides, and do not reflect changing local, state, and federal regulatory actions. The impending ban on methyl bromide and the possible loss of organophosphate, carbamate, and halogenated hydrocarbon nematicides undoubtedly will restrict or eliminate continued use of some of these compounds for nematode management in the future (Ristaino and Thomas, 1997). In many instances, research on alternative technology is only in preliminary phases, and transitional impacts from existing to alternative tactics have yet to be clearly established or quantified. For example, it is not clear the extent to which agricultural industries will change once methyl bromide is phased out of production and use by the year 2005. Producers will have to rely on alternative strategies and tactics that may be less effective than those currently employed. The proposed ban no doubt will create a pest control void, and uncertainty exists regarding the impacts on pests and cropping systems. In some analyses, the loss of methyl bromide is predicted to have substantial economic impact (Noling and Becker, 1994; Ristaino and Thomas, 1997; Spreen et al., 1995; Thomas, 1996). Another confounding factor is the fact that many organophosphate and carbamate nematicides are labeled as insecticides/nematicides. Chemicals such as aldicarb, carbofuran, ethoprop, fenamiphos, and terbufos are frequently applied to crops for insect control at rates that may or may not reduce damage caused by phytoparasitic nematodes. For some crops, the losses reported herein may underestimate potential yield losses due to nematodes and their interactions with other pests.

RESULTS AND DISCUSSION

Losses in field crops: Respondents were asked to provide information on 10 field crops which included alfalfa hay/hay, field corn, cotton, grain sorghum, peanut, rice, soybean, sugarcane, tobacco, and wheat. Many of these crops, such as cotton, peanut, and tobacco, are grown only in the southern United States, whereas others are less restricted in their distribution. Therefore, the number of states included for each crop varies considerably. Although field crops use the greatest land area for production, the low value of many of these commodities per hectare often precludes use of chemical control. Commodities such as cotton or tobacco, however, are highly reliant on nematicides. The uneven treatment of some crops in this report is, to some extent, a reflection of current interests of nematologists.

Field corn. Losses in corn production as a result of plant-parasitic nematodes for 28 corn-producing states varied from negligible for northern corn-producing states to 5% to 20% for selected southern states (Table 1). The most frequently reported genera of plant-parasitic nematodes on this crop are *Hoplolaimus, Meloidogyne,* and *Pratylenchus.* Several states also included *Belonolaimus longicaudatus, Longidorus breviannulatus,* and

TABLE 1. Species or genera of plant-parasitic nematodes effecting corn yield suppression in selected states, estimated percentages of crop loss, percentage of crop receiving a given management tactic, source of information, hectares of production, and value (U.S. dollars) estimate for the crop in 1994.

State	Nematode	Loss (%)	Management (%)[a]	Source[b]	Hectares (thousands)[c]	Value (millions of dollars)[d]
AL	*Pratylenchus* sp.	5–10		W. S. Gazaway	121	62
AR	Unspecified	0–1		T. Kirkpatrick, R. D. Riggs, R. T. Robbins	38	25
AZ	*Meloidogyne* sp. *Pratylenchus* sp.	0–2	N = 2	M. McClure	11	8
DE	*Longidorus breviannulatus* *Pratylenchus* sp.	0–1	N = 10, T = 90	B. Mulrooney	67	45
FL	*Belonolaimus longicaudatus* *Paratrichodorus* sp.	20		R. A. Dunn, J. Rich	48	16
GA	*Hoplolaimus columbus* *Meloidogyne* sp. *Paratrichodorus* sp. *Pratylenchus*	1–5	N = 10, T = 85	R. F. Davis	243	140
IA	*Hoplolaimus galeatus* *Longidorus breviannulatus* *Pratylenchus* sp. *Xiphema americanum*	0–1		G. Tylka	5,250	4,285
IL	*Hoplolaimus galeatus* *Longidorus breviannulatus* *Pratylenchus* sp. *Xiphema americanum*	2		D. Edwards	4,452	4,055
IN	*Longidorus breviannulatus*	0–1		J. Ferris	2,469	1,931
KS	*Belonolaimus longicaudatus* *Pratylenchus* sp.	1–5	N = 6, T = 94	D. J. Jardine, T. C. Todd	1,012	707
KY	*Pratylenchus* sp.	0–1		P. Vincell	526	372
LA	*Meloidogyne incognita* *Paratrichodorus* sp.	1–5	N = 5	C. Overstreet, E. C. McGawley	121	84
MD	*Meloidogyne* sp.	0–1		L. Krusberg, S. Sardanelli	186	113
ME	Unspecified	0–1		A. Henn	16	N/A
MI	*Longidorus breviannulatus*	1–5		G. W. Bird, F. Warner	954	582
MO	Unspecified	0–1		P. Donald, T. L. Niblack, J. A. Wrather	971	616
MS	Unspecified	0–1	N = 1	J. Fox, F. Killebrew, M. Patel	133	62
NE	Unspecified	0–1		T. Powers	3,360	2,688
NM	*Meloidogyne incognita* *Pratylenchus* sp.	1–5		S. Thomas	43	32
NC	*Belonolaimus longicaudatus* *Meloidogyne incognita* *Paratrichodorus minor*	1–5	N = 5	H. Duncan	372	203
OK	*Belonolaimus longicaudatus*	0–1		J. Damicone	52	45
OH	*Pratylenchus* sp.	0–1		R. Riedel	1,486	1,084
PA	*Helicotylenchus* sp. *Pratylenchus* sp.	0–1		N. S. H. Richwine	567	331
SC	*Helicotylenchus* sp. *Meloidogyne incognita* *Paratrichodorus minor* *Pratylenchus* sp.	5–10		S. Lewis, T. Keinath, P. Dukes, C. E. Drye, O. J. Dickerson, T. Melton, P. Smith	150	70
TX	*Hoplolaimus galeatus* *Paratrichodorus* sp. *Pratylenchus* sp.	0–1		J. L. Starr	870	599

TABLE 1. *Continued*

State	Nematode	Loss (%)	Management (%)[a]	Source[b]	Hectares (thousands)[c]	Value (millions of dollars)[d]
VA	*Hoplolaimus* sp. *Pratylenchus* sp.	1–5		P. M. Phipps	142	82
WI	Unspecified	0–1		J. Kurle	1,215	983
WA	*Paratrichodorus allius* *Pratylenchus* sp.	0–1		G. S. Santo	61	82
U.S.					29,509	22,992

[a] The percentage of crop with one of the following management practices: R = resistant cultivars, N = nematicide, and T = other.
[b] Source of information was personal communication.
[c] Anonymous (1995a). N/A = Data not available.
[d] Anonymous (1997).

Paratrichodorus spp. as pathogens contributing to corn-yield suppression. Although the corn cyst nematode, *Heterodera zeae,* has been detected in Virginia and Maryland, no losses for this nematode are projected at this time because of its apparent requirement for high soil temperatures (Windham, 1998). Losses in corn production may go unrecognized because of the extensive root system of corn and the lack of suitable control measures.

The 1987 bibliography (Society of Nematologists Crop Loss Assessment Committee, 1987) used National Agricultural Pesticide Impact Assessment Program reports to gather data on nematode losses in corn and soybean with or without the use of nematicides. Interestingly, the estimate for Iowa in 1985 was a loss of 4.2% with then-current nematicide usage or 5.5% without nematicides (Society of Nematologists Crop Loss Assessment Committee, 1987). This is in contrast to the 1994 estimate of 0% to 1% yield loss in this paper. The discrepancy may be a result of different reporting procedures, or it may reflect the decline in acreage of grain crops as a result of the conservation reserve program that removed some land from production in the 1980s. Changes in nematology and plant pathology personnel and research interests likely influenced responses in the north-central United States.

Management of nematodes in corn is achieved primarily with cultural practices rather than with nematicides or resistant hybrids. The percentage of the crop being treated with nematicides ranged from 0% to 10%, with no estimate for most states. The estimated value of the yield loss associated with the loss of nematicides for corn in North Carolina and Wisconsin was 7.5 and 0.47 million US$ (Pike et al., 1995). These dollar values are, however, based on survey data similar to those used in this report. Although efforts are under way to increase awareness of nematode-associated problems in corn, many state commodity organizations are reluctant to fund research or extension efforts that would increase corn production, and instead focus funding on utilization and marketing of this commodity.

Soybean. The current survey includes estimated losses from 25 soybean-producing states that ranged from 0% to 15% (Table 2). The soybean cyst nematode, *Heterodera glycines,* currently is considered to be the most serious soybean pathogen in the world causing an estimated loss in soybean yield of more than 3 million metric tons in the top 10 producing countries in 1994 (Wrather et al., 1997). *Meloidogyne* spp., *Pratylenchus* spp., and *Rotylenchulus reniformis* are the next most commonly cited plant-parasitic nematodes effecting soybean yield losses.

Although the current, yield-loss figure is similar to the estimates for 1985 (Society of Nematologists Crop Loss Assessment Committee, 1987), several states or regions have conducted surveys on the distribution of *H. glycines* that suggest that this nematode has become very widespread within the United States (Koenning and Barker, 1998; Lewis et al., 1993; Niblack et al., 1993; Sikora and Noel, 1991; Warner et al., 1994; Willson et

TABLE 2. Species or genera of plant-parasitic nematodes effecting soybean yield suppression in selected states, estimated percentage of crop loss, percentage of hectarage receiving a given management tactic, source of information, hectares of production, and value (U.S. dollars) estimate for the crop in 1994.

State	Nematode	Loss (%)	Management (%)[a]	Source[b]	Hectares (thousands)[c]	Value (millions of dollars)[d]
AL	*Heterodera glycines* *Rotylenchulus reniformis*	6		W. S. Gazaway	73	52
AR	*Heteroderea glycines*	1–5		T. Kirkpatrick, R. D. Riggs, R. T. Robbins	1,279	658
DE	*Heterodera glycines* *Meloidogyne* sp. *Pratylenchus* sp.	1–5	R = 80, T = 20	B. Mulrooney	89	43
FL	*Heterodera glycines* *Meloidogyne* sp.	9		Wrather (1995), J. Rich	18	7
GA	*Heterodera glycines* *Hoplolaimus columbus* *Meloidogyne* sp. *Rotylenchulus reniformis*	6–5	N = 10, T = 30, R = 80	Wrather (1995), R. F. Davis	194	84
IA	*Heterodera glycines*	10–15		G. Tylka	3,561	2,405
IL	*Heterodera glycines* *Pratylenchus* sp.	6–5		D. Edwards	3,855	2,407
IN	*Heterodera glycines*	1–5		J. Ferris	1,902	1,190
KS	*Heterodera glycines*	1–5	R = 2, T = 98	D. J. Jardine, T. C. Todd	870	391
KY	*Heterodera glycines* *Xiphinema* sp.	1–5		D. Hershman	486	239
LA	*Heterodera glycines* *Meloidogyne incognita* *Rotylenchulus reniformis*	5–10	R = 60, T = 20	E. C. McGawley, C. Overstreet	445	177
MD	*Heterodera glycines*	7	R = 75, N = 15	L. Krusberg, S. Sardanelli	231	105
MI	*Heterodera glycines*	1–5		G. W. Bird, F. Warner	627	309
MN	Unspecified	1		W. Stienstra	2,307	1,203
MS	*Heterodera glycines*	0–1		J. Fox, F. Killebrew, M. Patel	789	319
MO	*Heterodera glycines*	3		Wrather (1995)	1,873	941
NC	*Heterodera glycines* *Hoplolaimus columbus* *Meloidogyne* sp. *Pratylenchus brachyurus*	10–15	N = 0.01, R = 40, T = 70	S. Koenning	540	224
NE	*Heterodera glycines*	0–1		T. Powers	1,174	711
OH	*Heterodera glycines* *Meloidogyne hapla*	5–15		R. Riedel	1,615	956
OK	*Heterodera glycines* *Meloidogyne* sp.	0–1		J. Damicone	107	48
SC	*Heterodera glycines* *Hoplolaimus Columbus* *Meloidogyne arenaria* *Meloidogyne incognita*	10–15		Wrather (1995)	251	86
TN	*Heterodera glycines*	1–5	R = 75, T = 25, N = 0	Wrather (1995), L. D. Young	425	215
TX	*Heterodera glycines* *Meloidogyne* sp.	0–1		Wrather (1995)	81	35
VA	*Belonolaimus longicaudatus* *Heterodera glycines* *Paratrichodorus minor*	1–5		P. M. Phipps	210	89
WI	*Heterodera glycines*	0–1		J. Kurle	364	200
U.S.					25,067	13,756

[a] The percentage of crop with one of the following management practices: R = resistant cultivars, N = nematicide, and T = other.
[b] Unless otherwise specified, source was personal communication.
[c] Anonymous (1995a).
[d] Anonymous (1997).

al., 1996; Workneh et al., 1999; Young, 1990). The regional assessment of the prevalence of *H. glycines* and several other soybean pathogens (Workneh et al., 1999) for six north-central states provides insight into the seriousness of this particular nematode problem. The estimates in this paper from the north-central region are based, in part, on these published findings and likely provide a reasonably accurate estimate of yield losses from this single pathogen.

In addition to surveys on the distribution of *H. glycines,* there exists a considerable body of research published since the last bibliography in 1987 that provides for improved methodology in constructing estimated losses for this nematode. Researchers in several states have compared soybean yield as affected by resistant cultivars, and cropping systems (Francl and Dropkin, 1986; Koenning et al., 1993; MacGuidwin et al., 1995; Todd et al., 1995; Wheeler et al., 1997). The previous bibliography used information from USDA publications that included estimates with or without current nematicide usage similar to that reported for corn. The comparison of plots treated or not treated with aldicarb to estimate soybean losses due to nematodes is questionable in view of research findings that aldicarb may enhance soybean growth in the absence of pests (Barker et al., 1988).

Soybean disease-loss estimates are collated annually by the Southern Soybean Disease Workers for the southern United States and published in their proceedings (Wrather, 1995). Periodically, summaries of these estimates and those of the northern states have been published in *Plant Disease* (Doupnik, 1993; Wrather et al., 1995). These reports, based on survey data, are useful in that they establish a foundation for measurement of changes in disease prevalence over time.

In spite of substantial progress by plant breeders in developing nematode-resistant and tolerant soybean varieties (Young, 1996, 1998), estimates of soybean yield suppression in response to plant-parasitic nematodes in 1994 are greater than in the previous survey. This increase is likely due to the continued geographic spread and increased awareness of *H. glycines* as a major limiting factor in soybean production. Additionally, the continued change in race status of the *H. glycines* populations in response to the deployment of resistance genes also accounts for continued yield loss due to this nematode (Koenning and Barker, 1998). The use of resistant cultivars was listed most frequently as a management tactic, followed by ''other means'' as the next most-common method used. Many respondents indicated that either none or rarely 1% of the crop was treated with nematicides, although Georgia indicated 10% and Maryland 15%. Nematicide usage in soybean is currently at low levels due to the expense of the materials still labeled for nematode control and the low value of the commodity per hectare. Schmitt et al. (1987) demonstrated that chemical control of *H. glycines* with aldicarb was not profitable except when relatively low population densities of this nematode were present.

Wheat. More than 28 million ha of wheat were planted in 1994 (Table 3). Respondents from 21 states estimated yield losses of 0% to 5%. Data collected by Sasser and Freckman (1987) indicated a 7.0% yield loss worldwide. Despite the importance of wheat to the U.S. economy, little is known about the impact of plant-parasitic nematodes attacking the crop. Plant-parasitic nematodes known to damage wheat include *Heterodera avenae, Meloidogyne hapla, M. chitwoodi, Mesocriconema* spp., and *Pratylenchus* spp. (Armstrong et al., 1993; Griffin, 1993; McGawley and Overstreet, 1998; Mojtahedi et al., 1992; Smiley et al., 1994). Additionally, the cereal cyst nematode, *H. avenae,* has now been detected in five states. Yield losses specifically attributed to this nematode were reported only from the state of Washington. However, rotation and chemical trials conducted in Oregon demonstrated that *H. avenae* was an important constraint on yield (Smiley et al., 1994). Many of these nematodes have restricted either yield or plant growth when their numbers increased on wheat. Nematicide testing showed increased yield when carbofuran was applied in *Pratylenchus thornei*-infested fields (Armstrong et al., 1993).

TABLE 3. Species or genera of plant-parasitic nematodes causing wheat-yield loss in selected states, estimated percentage of crop loss, source of information, hectares of production, and value (U.S. dollars) estimate for the crop in 1994.

State	Nematode	Loss (%)	Source[a]	Hectares (thousands)[b]	Value (millions of dollars)[c]
AR	Unspecified	0–1	T. Kirkpatrick, R. D. Riggs, R. T. Robbins	344	129
AZ	*Pratylenchus* sp.	0–1	M. McClure	51	46
CA	*Meloidogyne* sp. *Pratylenchus* sp.	1–3	J. D. Radewald	263	162
DE	None	0	R. Mulrooney	26	11
FL	*Belonolaimus longicaudatus* *Paratrichodorus* sp.	5	J. Rich	10	2
GA	*Meloidogyne* sp. *Pratylenchus* sp.	0–1	R. F. Davis	187	62
KY	None	0	D. Hershman	170	78
LA	Unspecified	0–1	E. C. McGawley, C. Overstreet	40	8
MD	*Pratylenchus penetrans*	0–1	L. Krusberg, S. Sardanelli	79	37
MI	*Pratylenchus penetrans*	1–5	G. W. Bird, F. Warner	263	100
MN	None	0	W. Stienstra	1,133	238
MO	Unspecified	0–1	P. Donald, T. L. Niblack, J. A. Wrather	462	157
MS	Unspecified	0–1	J. Fox, F. Killebrew, M. Patel	85	21
NC	Unspecified	0–1	J. Bailey	243	91
NM	*Meloidogyne incognita*	0–1	S. Thomas	190	21
OK	*Pratylenchus* sp.	1–5	J. Damicone	2,979	488
SC	*Meloidogyne incognita* *Pratylenchus brachyurus*	1–5	S. Lewis, T. Keinath, P. Dukes, C. E. Drye, O. J. Dickerson, T. Melton, P. Smith	105	54
TX	*Meloidogyne* sp.	0–1	J. L. Starr	2,428	243
VA	None	0	P. M. Phipps	113	40
WA	*Heterodera avenae* *Meloidogyne* sp. *Pratylenchus* sp.	0–1	J. Wilson, G. S. Santo	1,133	525
U.S.				28,449	7,968

[a] Source was personal communication.
[b] Anonymous (1995a).
[c] Anonymous (1997a).

Rice. A number of nematode genera and species have been implicated as pathogens on rice (McGawley and Overstreet, 1998; Hollis and Keoboonrueng, 1984). The species reported to damage rice are in the genera *Aphelenchoides, Ditylenchus, Heterodera, Hirschmanniella, Meloidogyne,* and *Pratylenchus.* Losses reported for plant-parasitic nematodes on a worldwide basis have been estimated at 10% (Sasser and Freckman, 1987). By comparison, losses reported for the United States included in this report (Table 4) are very minor (1% or less). The most common nematode associated with losses or potential losses in the United States was *Aphelenchoides besseyi* (causal agent of white tip of rice).

Currently, very little research is being conducted on plant-parasitic nematodes in rice in the United States. Nematicides are not specifically used on rice for nematode management. A nematicide/insecticide, carbofuran, is used at low rates for rice water weevil control, but its impact on nematodes is not known. Rice is commonly grown in rotation with soybean in Louisiana, Mississippi, Texas, and Arkansas, whereas only about 30% of the rice grown in California is rotated with other crops.

Most cultivars of long-grain rice are considered to be resistant to *A. besseyi,* while short- and medium-grain cultivars are susceptible (Atkins and Marchetti, 1979). Popova et al. (1994) indicated that several

TABLE 4. Rice yield suppression in selected states as effected by plant-parasitic nematodes, estimated percentage of crop loss, percentage of hectarage receiving a given management tactic, source of information, hectares of production, and value (U.S. dollars) estimate for the crop in 1994.

State	Nematode	Loss (%)	Management (%)[a]	Source[b]	Hectares (thousands)[c]	Value (millions of dollars)[d]
AR	None	0	0	T. Kirkpatrick, R. D. Riggs, R. T. Robbins	558	528
CA	*Aphelenchoides besseyi*	0		B. Westerdahl	197	287
LA	*Aphelenchoides besseyi* *Mesocriconema* sp.	0–1	R = 95, T = 100	E. C. McGawley, C. Overstreet	220	198
MS	*Aphelenchoides besseyi*	0–1	T = 100	J. Fox, F. Killebrew, M. Patel, G. W. Lawrence	99	129
MO	Unspecified	0–1	0	P. Donald, T. L. Niblack, J. A. Wrather	53	43
TX	None	0	0	J. P. Krausz	144	151
U.S.					1,357	1,337

[a] The percentage of crop with one of the following management practices: R = resistant cultivars, N = nematicide, and T = other.
[b] Source was personal communication.
[c] Anonymous (1995a).
[d] Anonymous (1997).

U.S. cultivars were either immune or very resistant to the white-tip nematode. Additionally, fumigants used for insect control in stored rice (phostoxin) have been effective in eliminating *A. besseyi* from infected rice seed (McGawley et al., 1984) and may aid in management of this pest. Some states such as California have a certification program in effect to detect *A. besseyi* in grain shipments to other countries (R. Hackney, pers. comm.).

Grain sorghum. The most common nematodes reported from the United States associated with losses in grain sorghum are *Belonolaimus* spp., *Meloidogyne,* and *Pratylenchus* (Table 5). An extensive number of nematode species are associated with nematode losses in grain sorghum (McGawley and Overstreet, 1998; Starr, 1992; Swarup and Sosa-Moss, 1990). Worldwide losses to sorghum from nematodes were estimated at 6.9% (Sasser and Freckman, 1987). Losses reported for the states that grow 97% of the sorghum in the United States averaged about 1.5%, representing approximately a $21-million loss. South Dakota had the greatest losses, with estimates of 5% to 10%.

Reproduction of *M. incognita* on sorghum is variable. This nematode is reported as causing problems in Arizona and New Mexico (Table 5), but grain sorghum is considered very resistant to *M. incognita* in the southeastern states (Fortnum and Currin, 1988; Ibrahim et al., 1993; McSorley and Gallaher, 1991). Conflicting reports on the host status of grain sorghum to southern root-knot nematode may indicate regional differences in cultivars or nematode biotypes. Little research has been conducted with management of plant-parasitic nematodes in sorghum. Crop rotation is the only management tactic employed by producers to alleviate nematode-induced yield losses. In many areas sorghum is used as a rotation crop to manage nematodes that may be causing damage to other crops. Aldicarb and terbufos are two nematicides labeled for use on sorghum, but they are rarely applied for nematode control.

Sugarcane. Sugarcane losses attributed to plant-parasitic nematodes on a worldwide basis have been reported at 15.3% (Sasser and Freckman, 1987). The average loss estimated for the United States on this crop was 4% (Table 6). A number of nematodes are known to damage sugarcane, including a number of species of *Belonolaimus, Meloido-*

TABLE 5. Species or genera of plant-parasitic nematodes responsible for losses in grain sorghum production in selected states, percentage loss, percentage of crop receiving a given management tactic, source of information, production area, and crop value (U.S. dollars) for 1994.

State	Nematode	Loss (%)	Management (%)[a]	Source[b]	Hectares (thousands)[c]	Value (millions of dollars)[d]
AR	None	0	T = 100	T. Kirkpatrick, R. D. Riggs, R. T. Robbins	105	37
AZ	*Meloidogyne incognita* *Pratylenchus* sp.	0–1	0	M. McClure	N/A	N/A
GA	*Pratylenchus* sp.	0–1		R. F. Davis	26	5
KS	*Belonolaimus longicaudatus* *Meloidogyne* sp. *Tylenchorhynchus* sp.	0–1	T = 100	D. J. Jardine, T. C. Todd	1,295	462
LA	*Pratylenchus* sp.	1–5	T = 100	E. C. McGawley, C. Overstreet	49	18
MO	Unspecified	0–1		P. Donald, T. L. Niblack, J. A. Wrather	231	99
MS	*Pratylenchus zeae* *Quinisulcius acutus*	1	T = 100	G. W. Lawrence	30	11
NM	*Meloidogyne incognita* *Pratylenchus* sp.	1–5	0	S. H. Thomas	83	17
OK	*Belonolaimus longicaudatus*	0–1		J. Damicone	129	29
SD	*Paratrichodorus allius* *Tylenchorhynchus nudus*	5–10	0	J. D. Smolik	113	19
TX	*Pratylenchus* sp.	0–1	0	J. L. Starr	1,133	333
U.S.					3,955	1,324

[a] The percentage of crop with one of the following management practices: R = resistant cultivars, N = nematicide, and T = other.
[b] Source of information was personal communication.
[c] Anonymous (1995a). N/A = data not available.
[d] Anonymous (1997). N/A = data not available.

gyne, Paratrichodorus, Pratylenchus, Tylenchorhynchus, and *Xiphinema* (Birchfield, 1984; Spaull and Cadet, 1990; Williams, 1969). The most commonly reported species of plant-parasitic nematodes causing damage to sugarcane were *M. incognita* and *Pratylenchus* spp. (Table 6). Birchfield (1984) considered these nematodes as being the

TABLE 6. Estimated production losses in sugarcane caused by plant-parasitic nematodes in selected states, species or genera responsible, percent loss, percent of the crop receiving a given management tactic, source of information, hectarage in production, and crop value (U.S. dollars) in 1994.

State	Nematode	Loss (%)	Management (%)[a]	Source[b]	Hectares (thousands)[c]	Value (millions of dollars)[d]
FL	*Belonolaimus longicaudatus* *Meloidogyne incognita* *Pratylenchus* sp.	4	0	J. Rich, R. A. Dunn	179	457
HI	*Meloidogyne* sp. *Pratylenchus* sp.	0–1	T = 95	D. P. Schmitt, S. C. Nelson, B. S. Sipes	28	163
LA	*Meloidogyne incognita* *Paratrichodorus* sp. *Pratylenchus* sp.	5–10	N = 10	E. C. McGawley, C. Overstreet	162	240
TX	Unspecified	0–1	0	T. Isakeit, J. L. Starr	18	40
U.S.					418	901

[a] The percentage of crop with one of the following management practices: R = resistant cultivars, N = nematicide, and T = other.
[b] Source of information was personal communication.
[c] Anonymous (1996).
[d] Anonymous (1997).

most important nematode pathogens worldwide in sugarcane.

Sugarcane is grown as a primary and ratoon crop in the same location for 3–4 years, making nematode management difficult. A fallow period or cover crop is often used between crop cycles of sugarcane. Aldicarb, 1,3-dichloropropene, and ethoprop are labeled nematicides for use in sugarcane but are not widely used.

Some cultivars of sugarcane, such as CP 70-321, appear to be tolerant to several plant-parasitic nematodes (species of *Mesocriconema, Paratrichodorus,* and *Tylenchorhynchus*) compared to LCP 82-89, which was severely damaged at population densities that commonly occur in production fields (McGawley et al., 1997). Although there is no specific effort to develop root-knot-resistant cultivars, some cultivars released in Louisiana are resistant to this pest and a number of advanced breeding lines have been shown to be resistant (Anzalone and Birchfield, 1977).

Cotton. Data on cotton-yield suppression in relation to various diseases and plant-parasitic nematodes is compiled by the Beltwide Cotton Conference and published annually in their proceedings (Blasingame, 1995). Survey results indicated losses from 0% to 10% in response to plant-parasitic nematodes (Table 7). The most frequently cited species causing cotton-yield loss were *M. incognita* and *R. reniformis.* The Columbia lance nematode, *Hoplolaimus columbus,* was reported only from North Carolina, South Carolina, and Georgia. This nematode has since been found in Alabama (W.S. Gazaway, pers. comm.) and Louisiana (C. Overstreet, pers. comm.). The distribution of *R. reniformis* in the United States was determined by Heald and Robinson (1990), and damage functions for *M. incognita* and *R. reniformis* have been developed for several soil types in North Carolina (Koenning and Barker, 1996). Currently, the Cotton Foundation is sponsoring the Nematode Survey and Education Committee, which has developed maps on the distribution of plant-parasitic nematodes in cotton (Blasingame, 1993) and is in the process of developing damage thresholds for selected nematode species on cotton, based largely on the results of nematicide trials. Additionally, the prevalence and distribution of plant-parasitic nematodes in cotton has been documented for a number of states (Baird et al., 1996; Kinloch and Sprenkel, 1994; Martin et al., 1994; Robbins et al., 1989; Wrather et al., 1992). These efforts should permit a higher level of confidence for cotton-loss estimates than for other crops.

Tactics used for nematode management listed by respondents were primarily nematicides. Starr (1998) recently summarized cotton-nematode management as being highly dependent on nematicides with little or no use of resistant cultivars. Some resistance is available in cotton to *M. incognita,* and breeding lines tolerant to *R. reniformis* have been developed (Barker and Koenning, 1997; Cook et al., 1997; Ogallo et al., 1997). Nevertheless, the prospects for deploying resistance to reniform nematode in the near future are not favorable.

Peanut. Peanut-yield losses from the nine states reporting varied from 0%–1% up to 5%–10% (Table 8). Three states that accounted for more than 75% of the peanut hectarage, Alabama, Georgia and Texas, had the most confidence in their estimates of 8.0%, 5.5%, and 3.0% losses, respectively. The peanut and northern root-knot nematodes, *M. arenaria* and *M. hapla,* respectively, were most frequently mentioned as the causal organism, followed by *B. longicaudatus, Mesocriconema ornata,* and *Pratylenchus* spp. Peanut-disease losses were summarized annually in the Proceedings of the American Peanut Research and Education Society (Sturgeon, 1984), but these estimates have been discontinued (J. E. Bailey, pers. comm.).

Damage functions for many nematode species on peanut have been developed during the past 20 years in several peanut-producing states (Dickson, 1998). The use of damage functions should facilitate the development of more precise estimates of peanut losses associated with plant-parasitic nematodes. Nematicide usage in the states that responded varied from 1% to 70%.

TABLE 7. Species or genera of plant-parasitic nematodes effecting cotton-yield suppression in selected states, estimated percentage of crop loss, percentage of hectarage receiving a given management tactic, source of information, hectares of production, and value (U.S. dollars) estimate for the crop in 1994.

State	Nematode	Loss (%)	Management (%)[a]	Source[b]	Hectares (thousands)[c]	Value (millions of dollars)[d]
AL	*Meloidogyne incognita* *Rotylenchulus reniformis*	7		W. S. Gazaway	182	241
AZ	*Meloidogyne incognita* sp. *Pratylenchus* sp.	0–1		M. McClure	170	305
AR	*Meloidogyne incognita*	5–10		T. K. Kirkpatrick, R. D. Riggs, R. T. Robbins	397	576
CA	*Meloidogyne incognita*	1–4		Blasingame (1995)	443	1,138
FL	*Meloidogyne incognita* *Rotylenchulus reniformis*	1–5		J. Rich	28	36
GA	*Hoplolaimus columbus* *Meloidogyne incognita* *Rotylenchulus reniformis*	1–5	N = 30, T = 50	R. F. Davis	358	541
LA	*Meloidogyne incognita* *Rotylenchulus reniformis*	5–0	N = 70, T = 20	Blasingame (1995)	356	497
MS	*Meloidogyne incognita* *Rotylenchulus reniformis*	1–5		J. Fox, F. Killebrew, M. Patel	567	734
MO	*Meloidogyne incognita* *Rotylenchulus reniformis*	1–5		Blasingame (1995), Wrather et al. (1992)	133	195
NM	*Meloidogyne incognita*	1–5		S. Thomas	34	36
NC	*Belonolaimus longicaudatus* *Hoplolaimus columbus* *Meloidogyne incognita* *Rotylenchulus reniformis*	0–1	N = 90, T = 10	J. Bailey	194	289
OK	*Meloidogyne incognita*	0–1		J. Damicone	156	81
SC	*Hoplolaimus columbus* *Meloidogyne incognita* *Rotylenchulus reniformis*	5–10		S. Lewis, T. Keinath, P. Dukes, C. E. Drye, O. J. Dickerson, T. Melton, P. Smith	80	136
TN	*Meloidogyne incognita*	0–2		Blasingame (1995)	237	296
TX	*Meloidogyne incognita* *Rotylenchulus reniformis*	5		J. L. Starr	2,075	1,642
VA	*Belonolaimus longicaudatus*	0–1		P. M. Phipps	10	28
U.S.					5,552	6,797

[a] The percentage of crop with one of the following management practices: R = resistant cultivars, N = nematicide, and T = other.
[b] Source of information was personal communication unless otherwise specified.
[c] Anonymous (1995a).
[d] Anonymous (1997).

Other methods for control also were used in most states. Resistance to plant-parasitic nematodes in peanut, although in a developmental stage, is not currently available in commercially acceptable cultivars. Peanut cultivars with high levels of resistance to the peanut root-knot nematode, *M. arenaria,* may be available in a few years (Dickson, 1998).

Tobacco. Root-knot nematodes (*Meloidogyne* spp.) are the major nematode taxa that cause disease in U.S. tobacco production areas. In spite of widespread nematicide use, root-knot still decreases production from 0.5% to 5.0% of the flue-cured tobacco crop, and by as much as 10% in Connecticut (Table 9). Races 1 and 3 of *M. incognita* were the prevalent nematode pathogens parasitizing tobacco in North Carolina and South Carolina (Barker, 1989; Fortnum et al., 1984). Currently, more than 90% of the flue-cured tobacco grown in North Carolina is resistant to *M. incognita* races 1 and 3 as well as *M. arenaria* race 1, which implies that other races of *M. incognita* or other *Meloidogyne* spp. are now the most commonly found species (Melton et al., 1998). Only Pennsylvania identified *M. hapla* as a significant

TABLE 8. Species or genera of plant-parasitic nematodes causing peanut yield loss in selected states, estimated percentage of crop loss, percentage of crop receiving a given management tactic, source of information, hectares of production, and value (U.S. dollars) estimate for the crop in 1994.

State	Nematode	Loss (%)	Management (%)[a]	Source[b]	Hectares (thousands)[c]	Value (millions of dollars)[d]
AL	*Meloidogyne* sp. *Pratylenchus* sp.	8		A. K. Hagan	93.1	144.1
FL	*Meloidogyne arenaria* *Pratylenchus brachyurus*	5–15	T = 70, N = 50	R. A. Dunn, D. W. Dickson	37.3	58.3
GA	*Meloidogyne arenaria*	5–10	N = 35, T = 90	R. F. Davis	275.2	532.7
LA	*Mesocriconema* sp. *Pratylenchus* sp.	1–5	N = 50	E. C. McGawley, C. Overstreet	0.4	1.0
NM	*Pratylenchus brachyurus*	1–5	N = 1	S. Thomas	8.9	16.4
NC	*Meloidogyne arenaria* *Meloidogyne hapla* *Mesocriconema ornatum*	0–1	N = 60	J. Bailey	64.8	134.0
OK	*Meloidogyne hapla* *Pratylenchus brachyurus*	0–1		J. Damicone	42.0	80.9
SC	*Meloidogyne arenaria* *Mesocriconema ornata*	5–10		S. Lewis, T. Keinath, P. Dukes, C. E. Drye, O. J. Dickerson, T. Melton, P. Smith	5.5	9.9
TX	*Meloidogyne arenaria*	3		J. L. Starr	106.0	172.3
VA	*Belonolaimus longicaudatus* *Meloidogyne* sp. *Mesocriconema ornatum* *Pratylenchus* sp.	1–5		P. M. Phipps	38.0	80.1
U.S.					664.0	1,229.0

[a] The percentage of crop with one of the following management practices: R = resistant cultivars, N = nematicide, and T = other.
[b] Source of information was personal communication.
[c] Anonymous (1995a).
[d] Anonymous (1997).

nematode parasite of tobacco. The tobacco cyst nematode *G. tabacum,* though limited in geographic distribution, can cause severe losses in the broadleaf and shade tobacco of Connecticut (LaMondia, 1995) and the flue-cured areas of Virginia and North Carolina. This nematode is now found in five North Carolina counties at present (J. L. Imbriani, pers. comm.). Lesion nematodes, *Pratylenchus* spp., were listed as causing tobacco losses only in Tennessee.

Host-plant resistance is widely used in tobacco production to manage races 1 and 3 of *M. incognita* and race 1 of *M. arenaria.* Species and races of root-knot nematodes that cannot be managed with currently available resistant cultivars such as *M. arenaria* race 2, *M. javanica, M. hapla,* and *M. incognita* races 2 and 4 are increasing in importance (Barker, 1989; Fortnum et al., 1984). The presence of other root-knot nematode taxa complicates traditional crop rotation schemes because reproduction of different species of *Meloidogyne* varies with crop and cultivar. Species of *Meloidogyne* that are more aggressive on tobacco than *M. incognita,* such as *M. arenaria* and *M. javanica,* appear to be increasing in frequency in most flue-cured tobacco-producing states and may account for the higher-than-average losses reported for Florida.

Traditionally, flue-cured tobacco has been grown on farms with small allotments (ca. 10 ha of tobacco or fewer), allowing for long-interval rotation schemes. Crop rotation reduces the frequency and intensity of most soilborne diseases (Gooden et al., 1998). The decline in the number of allotment holders in most states, coupled with an increase in farm size (>50 ha of tobacco production), has reduced rotation intervals. As a consequence, the percentage of disease losses caused by endemic soilborne diseases such as black shank (*Phytophthora parasitica*

TABLE 9. Estimated production losses in tobacco caused by plant-parasitic nematodes in selected states, species or genera responsible, percent loss, percent of the crop receiving a given management tactic, source of information, hectarage in production, and crop value (U.S. dollars) in 1994.

State	Nematode	Loss (%)	Management (%)[a]	Source[b]	Hectares (thousands)[c]	Value (millions of dollars)[d]
CT	*Globodera tabacum*	5–10		J. LaMondia	0.6	4.3
FL	Unspecified	3–5	N = 50	R. A. Dunn, J. Rich	2.6	27.3
GA	*Meloidogyne arenaria* *Meloidogyne incognita* *Meloidogyne javanica*	0–1	N = 95, R = 85, T = 85	R. F. Davis	15.0	133.4
KY	*Meloidogyne* sp.	0–1		W. Nesmith	83.0	840.9
MO	Unspecified	0–1		P. Donald, T. L. Niblack, J. A. Wrather	1.4	14.7
NC	*Meloidogyne arenaria* *Meloidogyne incognita* *Meloidogyne javanica*	0–1	R = 40, N = 70, T = 20	T. A. Melton	108.9	1,025.1
PA	*Meloidogyne hapla.*	0–1		N. S. H. Richwine	3.6	19.7
SC	*Globodera tabacum* *Meloidogyne arenaria* *Meloidogyne incognita* *Meloidogyne javanica*	1–5		S. Lewis, T. Keinath, P. Dukes, C. E. Drye, O. J. Dickerson, T. Melton, P. Smith	19.4	182.7
TN	*Meloidogyne incognita* *Pratylenchus* sp.	0–1	T = 100, N = 100	S. Bost	24.4	248.4
VA	*Globodera tabacum*	0–1	N = 60, R = 75	C. S. Johnson	18.8	183.4
	Meloidogyne incognita	1–5	N = 60, R = 75	C. S. Johnson		
U.S.					272	2,779

[a] The percentage of crop with one of the following management practices: R = resistant cultivars, N = nematicide, and T = other.
[b] Source of information was personal communication.
[c] Anonymous (1995a).
[d] Anonymous (1997).

var. *nicotianae*) and bacterial wilt (*Ralstonia solanacearum*) has steadily increased since 1984 and comprised 91% and 81.4% of total disease losses in South Carolina and North Carolina, respectively, in 1998 (Gooden et al., 1998; Melton et al., 1999). The widespread use of multipurpose fumigants in the southeastern United States to suppress these soilborne pathogens has resulted in improved nematode control and lower losses to root-knot disease. Losses in South Carolina due to nematodes during the period (1984–1998) have steadily declined (Gooden et al., 1991, 1994, 1998; Kittrell et al., 1989).

Nematode-induced losses in the United States are most severe in flue-cured tobacco grown on sandy loam soils of the southeastern coastal plain. Survey respondents who reported management practices for this area indicated that nematicides were used on as much as 95% of the hectarage. In contrast, burley tobacco grown on fine-textured soils is rarely impacted by root-knot disease (W. C. Nesmith, pers. comm.). Because U.S. flue-cured tobacco is almost universally treated with multipurpose fumigants to suppress soilborne diseases, losses due to plant-parasitic nematodes in flue-cured tobacco in the United States is typically lower than that observed in many production areas of the world. The fumigation process effectively suppresses nematode population densities and reduces disease pressure from fungal and bacterial pathogens. If nematodes are not controlled, substantially higher losses would be expected. Crop losses in other production areas of the world have amounted to 15% of crop production (Schneider, 1991).

Hay/alfalfa hay. This category includes any crop grown and cut to produce hay, especially alfalfa, and does not include pastures or remnants of other crops such as peanuts that might be sold in this category. Of the 14 states reporting yield losses in hay, most reported losses of 0% to 1% (Table 10). Washington estimated yield losses for *Ditylenchus dipsaci* alone at 10% to 15%, and 5% to 10% for *M. chitwoodi, M. hapla,* and *Pratylenchus* spp. California reported a 5% yield loss and Utah a 5% to 10% yield loss, whereas Michigan reported suppression of yield due to plant-parasitic nematodes at 1% to 5%. The most common nematode problems appear to be disease caused by the stem and bulb nematode, *D. dipsaci,* root-knot nematodes, and *Pratylenchus* spp. Only Florida, reporting a 1% to 2% yield loss in hay included *B. longicaudatus* as a limiting factor for this crop.

These yield-loss estimates may be conservative since a number of nematode species parasitize alfalfa and cause significant yield reductions (Griffin, 1998). No nematicides are currently labeled for use in alfalfa and the low value of the crop per hectare makes their usefulness doubtful (Griffin, 1998). Estimates based on nematicide trials are not generally available, although several researchers have demonstrated increased growth as a result of nematicide treatment (Thies et al., 1992; Townshend, 1989; Willis and Thompson, 1979). Additionally, since alfalfa is often grown as a perennial crop, estimates of yield loss are difficult to obtain (Noling and Ferris, 1987). Nematode management in hay crops is generally restricted to fallow, crop rotation, or the use of resistant cultivars (Griffin, 1998).

TABLE 10. Estimated production losses in hay/alfalfa hay as a result of plant-parasitic nematodes in selected states, nematode species or genera, percent crop loss, percentage of crop receiving a particular management tactic, source of information, area in production, and crop value (U.S. dollars) in 1994.

State	Nematode	Loss (%)	Management (%)[a]	Source[b]	Hectares (thousands)[c]	Value (millions of dollars)[d]
AR	Unspecified	0–1		T. Kirkpatrick, R. D. Riggs, R. T. Robbins	455	136
AZ	*Ditylenchus dipsaci*	0–1	T = 100	M. A. McClure	8	134
CA	*Ditylenchus dipsaci* *Meloidogyne* sp.	5		J. D. Radewald	595	853
FL	*Belonolaimus longicaudatus* *Meloidogyne* sp.	1–2		R. A. Dunn	97	71
LA	Unspecified	0–1	0	E. C. McGawley, C. Overstreet	117	40
MI	*Meloidogyne hapla* *Pratylenchus penetrans*	1–5		G. W. Bird, F. Warner	567	340
MN	Unspecified	0–1	R = 5	W. Stienstra	931	532
MO	Unspecified	0–1		P. Donald, T. I. Niblack, J. A. Wrather	1,356	445
NM	*Meloidogyne incognita*	0–1		S. Thomas	105	173
OK	*Ditylenchus dipsaci* *Pratylenchus* sp.	0–1		J. Damicone	890	273
PA	*Pratylenchus* sp.	0–1		N. S. H. Richwine	777	461
TN	Unspecified	0–1		S. Bost	688	194
UT	*Ditylenchus dipsaci* *Meloidogyne hapla* *Meloidogyne incognita* *Pratylenchus* sp.	5–10		G. Griffin	277	197
WA	*Ditylenchus dipsaci*	1–5		J. Wilson	287	269
	Meloidogyne hapla	10–15	R = 70	G. S. Santo		
	Meloidogyne sp.	5–10	R = 25	G. S. Santo		
	Mesocriconema sp.					
	Pratylenchus sp.					
U.S.					23,773	11,114

[a] The percentage of crop with one of the following management practices: R = resistant cultivars, N = nematicide, and T = other.
[b] Source of information was personal communication.
[c] Anonymous (1995a).
[d] Anonymous (1997).

Vegetable crop losses: Twenty-seven states have reported loss estimates for vegetables, a significant enhancement from the three states reporting in the last bibliography (Society of Nematologists Crop Loss Assessment Committee, 1987). Respondents were asked about particular classes of vegetables that included solanaceous vegetables (bell pepper, tomato, Irish potato, and eggplant [Table 11]), cucurbits (cantaloupe, honeydew melon, watermelon, and cucumbers [Table 12]), phaseolus vegetables (dry bean, fresh snap bean, processing snap bean, and peas [Table 13]), cruciferous composite and umbelliferous vegetables (broccoli, Brussels sprouts, cabbage, carrot, cauliflower, celery, and lettuce [Table 14]), and miscellaneous vegetables (sweet corn, sweetpotato, onion, spinach, and taro [Table 15]). Ranges of estimated percentage of losses were provided by state respondents with no consideration given to nematode management costs incurred to avoid or minimize nematode-induced yield impacts.

Vegetable crop loss estimates provided by each respondent reflect a local summary of physical and environmental circumstances. For example, some of the highest loss estimates for any crop category were consistently reported from Hawaii, a tropical environment favoring high nematode damage potential. Yet, the smallest producing hectarage of any crop category was also consistently reported from Hawaii. Statewide estimates should not be extrapolated to provide national averages of crop loss without consideration of total hectarage in production. Consequently, we report for vegetable losses: (i) the average of the percent crop loss estimates among reporting states, and (ii) the percent loss of total area under cultivation in the United States. Overall losses in producing hectarage were computed as the sum of the products of reported percentage of loss and numbers of hectares planted for each state and crop category.

Considering the number and locations of respondents, a range of 18.9% (Solanaceae) to 95.3% (Cucurbitaceae) of total U.S. hectarage for the five major vegetable categories is estimated to be represented by this survey. Average percentage yield losses for any vegetable crop category ranged from 4% (Solanaceae) to 8% (miscellaneous vegetables). Overall, an average percent vegetable loss due to nematodes on a national basis was 5.2%, less than half the U.S. average loss of 11% reported in the previous 1971 bibliography (Feldmesser, 1971). Losses in terms of area under cultivation summarized for all five major crop categories reflect an overall U.S. average of 7.2% of all vegetable production lost due to plant-parasitic nematodes. Highest proportional losses in producing hectarage for any particular vegetable crop were those of solanaceous vegetables (9.4%) and lowest (5.3%) for cruciferous vegetables. In some instances, vegetable losses were not uniformly distributed among states. For example, more than two-thirds of the total loss in solanaceous vegetables was reported from Maine and Michigan. In other states, however, tomato and other solanaceous crops appear to be extensively grown under plastic mulch in fumigated soil, which results in little or no damage by nematodes.

Host-plant resistance was not reported by state respondents as a nematode management tactic for most vegetable crop categories. For example, use of plant resistance was not identified as a nematode management tactic by any respondent for cucurbitaceous, leguminous, or cruciferous vegetables. The use of plant resistance as a tactic for nematode management was reported only for home gardens in Louisiana, processed tomatoes in California, and solanaceous vegetables in Georgia, Louisiana, and Maryland. This situation probably reflects the unavailability of resistant cultivars for many crop and nematode combinations, as well as the presence of mixed populations of nematode species in many fields.

Nematicide usage was not reported as the exclusive tactic for nematode management in any state or vegetable crop category. The extent to which nematicides were used appeared to correspond to crop susceptibility level (cucurbits, for example) and (or) crop value (e.g., fresh-market tomato). Vegetable losses to plant-parasitic nematodes tended

TABLE 11. Species or genera of plant-parasitic nematodes effecting production losses in solanaceous vegetables (bell pepper, tomato, eggplant, and Irish potato) in selected states, estimated percentage of crop loss, percentage of hectarage receiving a given management tactic, source of information, hectares of production, and value (U.S. dollars) estimate for the crop in 1994.

State	(Crop) Nematode	Loss (%)	Management (%)[a]	Source[b]	Hectares (thousands)[c]	Value (millions of dollars)[d]
AL	*Meloidogyne* sp.	3		S. Kara	4.2	23.4
AR	*Meloidogyne* sp.	3		T. Kirkpatrick	4.0	9.9
CA	(bell pepper) *Meloidogyne* sp.	0–3	N = 30	J. D. Radewald	9.7	145.1
	(fresh tomato) *Meloidogyne* sp.	2	N = 80	J. D. Radewald	15.3	248.9
	(processed tomato) *Meloidogyne* sp.	10–20	R = 30, N = 25	J. D. Radewald	128.3	655.6
	(potato) *Meloidogyne* sp.	5		J. D. Radewald	16.6	164.9
CT	*Meloidogyne* sp. *Pratylenchus* sp.	1–5		J. LaMondia	0.2	N/A
DE	*Meloidogyne* sp. *Pratylenchus* sp.	0–1		B. Mulrooney	2.4	6.9
GA	*Meloidogyne* sp.	1–5	N = 75, T = 50, R = 15	Bertrand (1994)	6.1	35.0
HI	*Meloidogyne* sp.	10–20	N = 10	D. P. Schmitt, S. C. Nelson, B. S. Sipes	0.1	4.1
KY	*Meloidogyne* sp.	0–1		W. C. Nesmith	0.8	2.8
LA	*Meloidogyne incognita*	1–5	R = 20, N = 20	E. C. McGawley, C. Overstreet	1.0	7.5
MD	*Meloidogyne* sp.	1–5	R = 80, N = 20	L. Krusberg, S. Sardanelli	1.7	12.0
ME	*Pratylenchus* sp.	5–10		A. Henn	32.8	91.5
MI	*Meloidogyne hapla* *Pratylenchus penetrans*	5–10		G. W. Bird, F. Warner	20.5	103.0
MS	Unspecified	0–1		J. Fox, F. Killebrew, M. Patel	0.4	N/A
NC	*Meloidogyne arenaria* *Meloidogyne hapla* *Meloidogyne incognita* *Meloidogyne javanica*	0–1	N = 5	S. Koenning	10.6	33.3
NH	*Meloidogyne* sp.	0–1		C. Smith	0.2	N/A
NM	*Meloidogyne incognita*	5–10	N = 30	S. Thomas	14.0	N/A
PA	*Meloidogyne hapla*	0–1		N. S. H. Richwine	1.7	42.3
SC	*Meloidogyne arenaria* *Meloidogyne incognita* *Meloidogyne javanica*	1–5		S. Lewis, T. Keinath, P. Dukes, C. E. Drye, O. J. Dickerson, T. Melton, P. Smith	1.6	35.7
TN	*Meloidogyne hapla* *Meloidogyne incognita*	0–1	T = 100	S. Bost	1.7	24.2
UT	*Meloidogyne* sp.	1–5		G. Griffin	2.5	8.1
VA	*Meloidogyne* sp.	1–5		R. E. Baldwin	6.3	52.5
WA	(potato) *Meloidogyne hapla* *Mesocriconema* sp. *Pratylenchus* sp.	5–10	N = 75, T = 50	G. S. Santo	61.5	422.4
U.S.					1,817	4,973

[a] The percentage of crop with one of the following management practices: R = resistant cultivars, N = nematicide, and T = other.

[b] Source of information was personal communication.

[c] Anonymous (1995a).

[d] Anonymous (1997). N/A = data not available.

TABLE 12. Estimated production losses in cucurbits (cantaloupe, honeydew, watermelon, and cucumber) in reporting states in response to plant-parasitic nematodes, nematode species or genera, percent loss, percent of crop receiving a given management tactic, source of information, area in production, and estimated value (U.S. dollars) in 1994.

State	(Crop) Nematode	Loss (%)	Management (%)[a]	Source[b]	Hectares (thousands)[c]	Value (millions of dollars)[d]
AL	*Meloidogyne* sp.	3		S. Kara	3.1	5.8
AZ	*Meloidogyne* sp.	1–5	N = 50	M. A. McClure	9.7	82.7
CA	(cucumber) *Meloidogyne* sp.	5–10		J. D. Radewald	4.0	31.7
	(watermelon) *Meloidogyne* sp.	5		J. D. Radewald	6.9	73.2
	(cantaloupe) *Meloidogyne* sp.	10	N = 13	J. D. Radewald	32.1	224.3
DE	*Meloidogyne* sp.	1–5		B. Mulrooney	0.7	4.2
FL	*Belonolaimus longicaudatus* *Meloidogyne* sp. *Rotylenchulus reniformis*	3–5	N = 20, T = 75	R. A. Dunn	20.7	144.3
GA	*Meloidogyne* sp.	5–10	N = 80, T = 75	R. F. Davis	19.6	82.3
HI	*Meloidogyne* sp.	5–10		B. Sipes, D. P. Schmitt	2.2	3.0
IN	*Meloidogyne hapla* *Meloidogyne incognita*	5–10		J. Ferris	2.3	8.0
KY	*Meloidogyne* sp.	0–1		W. S. Nesmith	0.2	N/A
LA	*Meloidogyne incognita*	5–10	N = 10, T = 50	E. C. McGawley, C. Overstreet	0.8	2.6
MD	*Meloidogyne incognita*	1–5	N = 50, T = 50	L. Krusberg, S. Sardanelli	2.5	10.9
MI	*Pratylenchus penetrans*	1–5		G. W. Bird, F. Warner	12.3	33.1
MO	*Meloidogyne incognita*	0–1		P. Donald	2.5	15.9
MS	*Meloidogyne* sp.	0–1		J. Fox, F. Killebrew, M. Patel	2.8	7.1
NH	*Meloidogyne* sp.	0–1		C. Smith	0.6	N/A
NC	*Meloidogyne* sp.	5–10	N = 20, T = 30	S. Koenning	23.5	40.0
OK	*Meloidogyne* sp.	0–1		J. Damicone	3.6	7.8
SC	*Meloidogyne incognita*	5–10		S. A. Lewis, T. Keinath, P. Dukes, C. E. Drye, O. J. Dickerson, T. Melton, P. Smith	7.9	20.6
TX	*Meloidogyne* sp. *Rotylenchulus reniformis*	5–10		M. Black, T. A. Lee, T. Isakeit	34.7	166.6
VA	*Meloidogyne* sp.	0–1		R. E. Baldwin	4.1	9.1
U.S.					206	1,067

[a] The percentage of crop with one of the following management practices: R = resistant cultivars, N = nematicide, and T = other.
[b] Source of information was personal communication.
[c] Anonymous (1995a).
[d] Anonymous (1997). N/A = data not available.

to decrease with increased nematicide use. Nematicide usage as reported, however, represented no more than 1% to 3.3% of total U.S. hectarage for any major vegetable category. Evidently, nematicide usage was coupled with use of resistant crop cultivars and other tactics, since control tactics for some crops added up to more than 100%. Although these tactics were not well characterized, it is assumed they included use of nonhost cover crops, tillage practices, crop rotation, or avoidance of moisture, nutritional, and other pest stresses.

The respondents also were asked to identify the most damaging genera of nematodes in their state for each specific crop category. The genus of nematode most consistently identified was *Meloidogyne*. The genus *Pratylenchus* was reported as a principal nematode pathogen for most northern states. Al-

TABLE 13. Species or genera of plant-parasitic nematodes effecting production losses in selected leguminous vegetable crops (dry bean, fresh snap bean, processed snap bean, lima bean, and pea) by reporting states, estimated percentage of crop loss, percentage of hectarage receiving a given management tactic, source of information, hectares of production, and value (U.S. dollars) estimate for the crop in 1994.

State	(Crop) Nematode	Loss (%)	Management (%)[a]	Source[b]	Hectares (thousands)[c]	Value (millions of dollars)[d]
AL	*Hoplolaimus galeatus* *Meloidogyne* sp. *Rotylenchulus reniformis*	5–10		K. Kara	4.5	N/A
CA	(dry and fresh beans) *Meloidogyne* sp.	5–7		J. D. Radewald	57.6	126.4
	(lima bean) *Meloidogyne* sp.	5		J. D. Radewald	2.8	N/A
DE	*Meloidogyne* sp.	1–5		B. Mulrooney	3.2	N/A
FL	*Belonolaimus longicaudatus* *Meloidogyne* sp. *Rotylenchulus reniformis*	5–10	N = 20	R. A. Dunn, R. Inserra	12.1	53.8
GA	*Meloidogyne* sp.	1–5	N = 90, T = 100	Bertrand (1995)	5.7	16.0
HI	*Meloidogyne* sp. *Rotylenchulus reniformis*	1–5	T = 5	D. P. Schmitt, B. S. Sipes	0.1	0.3
LA	*Meloidogyne incognita*	5–10	T = 10	E. C. McGawley, C. Overstreet	1.2	3.5
MD	*Meloidogyne incognita*	1–5	T = 100	L. Krusberg, S. Sardanelli	1.0	2.1
ME	*Pratylenchus* sp.	1–5		A. Henn	0.4	N/A
MI	(dry bean) *Heterodera glycines* *Pratylenchus penetrans*	5–10		G. W. Bird, F. Warner	157.8	126.8
	(snap bean) *Pratylenchus penetrans*	1–5		G. W. Bird, F. Warner	1.0	2.3
MS	Unspecified	0–1		J. Fox, F. Killebrew, M. Patel	0.2	N/A
MO	*Heterodera glycines* *Meloidogyne incognita*	0–1		P. Donald	0.4	N/A
NC	*Heterodera glycines* *Meloidogyne* sp.	5–10	N = 0, T = 40	S. Koenning	3.0	7.2
NM	*Meloidogyne incognita*	1–5	N = 10	S. Thomas	5.3	6.5
SC	Unspecified	10–15		S. Lewis, T. Keinath, P. Dukes, C. E. Drye, O. J. Dickerson, T. Melton, P. Smith	2.6	N/A
TN	*Pratylenchus* sp.	0–1	T = 100	S. Bost	4.0	11.5
VA	*Meloidogyne* sp. *Pratylenchus* sp.	0–1		R. E. Baldwin	2.4	5.9
WA	(dry bean) *Meloidogyne hapla* *Mesocriconema* sp. *Pratylenchus* sp.	1–5	0	G. S. Santo	16.2	18.1
	(dry pea) *Meloidogyne chitwoodi* *Meloidogyne hapla* *Pratylenchus* sp.	1–5	0	G. S. Santo	32.8	12.7
	(green pea) *Heterodera goettingiana*	5–10	T = 25	G. S. Santo	24.6	33.8
U.S.					979	1,041

[a] The percentage of crop with one of the following management practices: R = resistant cultivars, N = nematicide, and T = other.

[b] Source of information was personal communication unless otherwise indicated.

[c] Anonymous (1995b).

[d] Anonymous (1997). N/A = data not available.

TABLE 14. Estimated production losses in cruciferous, composite, and umbelliferous vegetable crops (broccoli, cabbage, cauliflower, carrots, celery, and lettuce) in reporting states in response to plant-parasitic nematodes, nematode species or genera, percent loss, percent of crop receiving a given management tactic, source of information, area in production, and estimated value (U.S. dollars) in 1994.

State	(Crop) Nematode	Loss (%)	Management (%)[a]	Source[b]	Hectares (thousands)[c]	Value (millions of dollars)[d]
AL	*Meloidogyne* sp.	2		K. Kara	1.1	N/A
CA	(broccoli) *Heterodera* sp.	5–7		J. D. Radewald	46.5	26.0
	(Brussels sprouts) *Heterodera* sp.	10		J. D. Radewald	N/A	N/A
	(cabbage) *Heterodera* sp.	5		J. D. Radewald	4.2	55.7
	(carrots) *Meloidogyne* sp.	5	N = 22	J. D. Radewald	38.2	193.7
	(cauliflower) *Heterodera* sp.	10	N = 6	J. D. Radewald	16.8	144.9
	(celery) *Meloidogyne* sp.	1–2		J. D. Radewald	9.9	181.7
	(lettuce) *Longidorus africanus* *Meloidogyne* sp. *Tylenchorhynchus* sp.	3–5		J. D. Radewald	81.3	872.5
FL	*Belonolaimus longicaudatus* *Heterodera schachtii* *Meloidogyne* sp.	3–5		R. A. Dunn	7.1	52.9
GA	*Meloidogyne* sp.	0–1	N = 10, T = 50	R. F. Davis	3.6	24.3
HI	*Heterodera* sp. *Meloidogyne* sp. *Rotylenchulus reniformis*	20–30	T = 25	D. P. Schmitt, B. S. Sipes	0.5	3.3
KY	*Meloidogyne* sp.	0–1		W. S. Nesmith	0.4	N/A
LA	*Meloidogyne incognita*	1–5	T = 10	E. C. McGawley, C. Overstreet	1.8	4.6
MD	*Meloidogyne incognita* *Pratylenchus penetrans*	0–1	N = 60, T = 40	L. Krusberg, S. Sardanelli	0.3	1.0
MI	(cauliflower) *Pratylenchus penetrans*	0–1		G. W. Bird, F. Warner	0.3	3.3
	(carrots) *Heterodera carotae* *Meloidogyne hapla*	15–20		G. W. Bird, F. Warner	17.3	24.8
	(celery) *Meloidogyne hapla*	5–10		G. W. Bird, F. Warner	1.1	14.7
	(lettuce) *Meloidogyne hapla*	5–10		G. W. Bird, F. Warner	0.2	N/A
MS	Unspecified	0–1		J. Fox, F. Killebrew, M. Patel	0.2	N/A
NC	*Meloidogyne* sp.	0–1		S. Koenning	7.8	N/A
OK	*Meloidogyne* sp.	1–5		J. Damicone	0.4	N/A
SC	*Meloidogyne incognita*	10–15		S. Lewis, T. Keinath, P. Dukes, C. E. Drye, O. J. Dickerson, T. Melton, P. Smith	1.8	N/A
TX	*Meloidogyne* sp.	0–1		M. Black, T. Isakeit	22.6	58.8
VA	*Meloidogyne* sp.	0–1		R. E. Baldwin	1.0	N/A
WA	(carrot) *Meloidogyne hapla*	1–5	N = 50	G. S. Santo	3.2	25.4
U.S.					374	2,053

[a] The percentage of crop with one of the following management practices: R = resistant cultivars, N = nematicide, and T = other.

[b] Source of information was personal communication.

[c] Anonymous (1995b). N/A = data not available.

[d] Anonymous (1997). N/A = data not available.

TABLE 15. Species or genera of plant-parasitic nematodes effecting production losses in miscellaneous vegetables (onions, sweet corn, sweet potato, spinach, and home gardens) by reporting states, estimated percentage of crop loss, percentage of hectarage receiving a given management tactic, source of information, hectares of production, and value (U.S. dollars) estimate for the crop in 1994.

State	(Crop) Nematode	Loss (%)	Management (%)[a]	Source[b]	Hectares (thousands)[c]	Value (millions of dollars)[d]
CA	(onion) *Trichodorus* sp.	5		J. D. Radewald	3.9	84.9
	(spinach) *Heterodera* sp.	5		J. D. Radewald	15.4	44.8
	(sweet potato) *Meloidogyne* sp.	10		J. D. Radewald	2.9	42.2
FL	(home gardens) *Belonolaimus longicaudatus* *Meloidogyne* sp. *Paratrichodorus* sp.	15–20		R. A. Dunn	N/A	N/A
HI	(Taro) *Meloidogyne* sp.	20–25	T = 20	D. P. Schmitt, S. C. Nelson, B. S. Sipes	0.5	N/A
	(sweet potato) *Meloidogyne* sp. *Rotylenchulus reniformis*	5–10	T = 5	D. P. Schmitt, S. C. Nelson, B. S. Sipes	0.1	N/A
	(onion) *Meloidogyne* sp.	5–10	T = 5	D. P. Schmitt	0.3	N/A
LA	(home gardens) *Meloidogyne incognita*	10–15	R = 20	E. C. McGawley, C. Overstreet	20.3	117.0
	(sweet potato) *Meloidogyne incognita* *Rotylenchulus reniformis*	5–10	N = 70	E. C. McGawley, C. Overstreet	7.3	40.4
MI	(sweet corn) *Pratylenchus penetrans*	1–5		G. W. Bird, F. Warner	5.9	15.3
NC	(sweet potato) *Meloidogyne* sp.	5–10	T = 80	S. Koenning	12.1	55.3
NM	(onion) *Meloidogyne incognita*	1–5		S. Thomas	3.4	34.4
OK	(sweet potato) *Meloidogyne* sp.	1–5		J. Damicone	5.1	N/A
SC	(sweet potato) *Meloidogyne* sp.	5–10		P. D. Dukes	1.8	2.8
TX	(sweet potato) *Meloidogyne* sp.	5–7		G. Philley	2.3	10.4
VA	(spinach) *Pratylenchus* sp.	0–1		P. M. Phipps	0.8	1.7
WA	(onion) *Meloidogyne hapla* *Mesocriconema* sp. *Paratrichodorus allius*	1–5	N = 10, T = 5	J. Wilson, G. S. Santo	4.8	62.9
	(sweet corn) *Paratrichodorus allius* *Pratylenchus* sp.	0–1	0	G. S. Santo	30.9	53.0
U.S.					241	1,232

[a] The percentage of crop with one of the following management practices: R = resistant cultivars, N = nematicide, and T = other.

[b] Source of information was personal communication.

[c] Anonymous (1995b). N/A = data not available.

[d] Anonymous (1997). N/A = data not available.

though reported considerably less frequently, *Heterodera* was also identified as genus of plant-parasitic nematode effecting yield loss, particularly within the cruciferous vegetable crop category. The reniform nematode, *R. reniformis,* was reported less frequently and then only from the southeastern states and Hawaii. The sting nematode, *B. longicaudatus,* was reported only as a significant nematode pest from Florida. The relative importance of the various nematode genera as pathogens corresponds with earlier reports (Sasser and Freckman, 1987).

Fruits and nuts: The current survey, unlike the last assessment, reports responses from experts in 21 states, rather than 5, for losses in fruits and nuts. The survey of fruit and nut crops includes a large number of crops, although many were not included. The geographic distribution, limited hectarage, and relatively minor importance of many specialty commodities precludes their inclusion in the current report. Crops on which information was received include almond, apple, apricot, avocado, banana, blueberry, brambles, citrus, cherry, coffee, fig, grape, guava, macadamia, nectarine, olive, papaya, peach, pear, pistachio, plum, prune, raspberry, strawberry, walnut, and pecan (Table 16). This section mentions only a few of the crops in order to make certain generalizations about nematode-associated losses.

Current crop-loss assessments on perennial fruit and nut crops represent, at best, educated guesses since we no longer have nematicides available that are highly effective against nematode populations at labeled rates without harmful effects to the host tree. In 1994, approximately 1.49 million ha in the United States were planted with fruit and nut crops, with a total fruit production value of about $8.5 billion (Anonymous, 1996). Estimated production losses varied considerably from state to state and crop to crop, but in major crop production areas nematode-related problems remained significant. For example, grape production suffered losses mainly due to root-knot and dagger nematodes, while nuts, stone-fruit, and pome-fruit producers suffered losses due to lesion and (or) ring nematodes. To illustrate the magnitude of non-realized production value, a 5% decline in 1994 almond production equaled approximately 16.8 million kg worth $90 million. A conservative estimate of 15% loss in California grape production is equivalent to $250 million in non-realized production value.

The difficulty in relating crop losses to nematode damage is especially complicated when nematode problems are caused or intensified by interactions with biotic or abiotic factors. For example, peach trees parasitized by *Mesocriconema xenoplax* are predisposed to *Pseudomonas syringae* and cold injury, which can lead to peach tree short-life syndrome in the southeastern United States. This disease complex has resulted in a total loss in potential revenue of approximately $6 million per year in South Carolina alone (Miller, 1994). Several *Xiphinema* spp. can reduce tree vigor of stone fruits but are even more important as vectors of nepoviruses such as cherry rasp leaf virus, peach rosette mosaic virus, and tomato ringspot virus (Brown et al., 1993).

Since the 1981 U.S. ban of DBCP (dibromochloropropane) as a soil fumigant, stone- and pome-fruit production has changed from almost exclusively nematicide-reliant to integrated pest management strategies (Nyczepir and Becker, 1998). The use of nematode-resistant or tolerant rootstocks, certification programs for nematode-free nursery trees, better orchard management, and tree health practices has helped reduce nematode problems. For example, root-knot nematodes have become less of a problem to the stone-fruit industry because of nematode-resistant rootstocks. However, these rootstocks are susceptible to lesion and ring nematodes. Losses due to plant-parasitic nematodes in citrus on a world basis were reported as 14.2% (Sasser and Freckman, 1987). Currently, losses in citrus in the United States are relatively low (Table 16). The good performance of trifoliate orange and some of its hybrids in the presence of the citrus strain of *Tylenchulus semipenetrans* and *Phytophthora* spp. has limited slow decline and citrus replant problems. In California, approximately 80% of citrus planted in the last 10 years and approximately 50% of all citrus trees have tolerant or resistant rootstocks (J. A. Menge, pers. comm.). Likewise, in Florida, widespread replanting with citrus nematode-resistant rootstocks has reduced the incidence of *T. semipenetrans,*

TABLE 16. Estimated production losses in various fruit and nut crops[a] caused by plant-parasitic nematodes in responding states, responsible species or genera, percent loss, percent of crop utilizing a particular management strategy, source of information, area in crop production, and estimated value (U.S. dollars) in 1994.

State	(Crop)[a] Nematode	Loss (%)	Management (%)[b]	Source[c]	Hectares (thousands)[d]	Value (millions of dollars)[e]
AR	(apple) Unspecified	0–1		T. Kirkpatrick, R. D. Riggs, R. T. Robbins	0.5	0.6
	(grape) Unspecified	0–1		T. Kirkpatrick, R. D. Riggs, R. T. Robbins	0.5	2.6
	(peach) Unspecified	1–5		T. Kirkpatrick, R. D. Riggs, R. T. Robbins	1.3	2.0
	(pecan) Unspecified	0–1		T. Kirkpatrick, R. D. Riggs, R. T. Robbins	2.2	1.4
	(strawberry) Unspecified	1–5		T. Kirkpatrick, R. D. Riggs, R. T. Robbins	0.1	0.3
AZ	(citrus) *Tylenchulus semipenetrans*	5–10		M. A. McClure	15.2	53.0
CA	(almond) *Mesocriconema xenoplax* *Pratylenchus* sp.	5–10		M. McKenry	178.0	900.3
	(apple) *Meloidogyne* sp. *Pratylenchus* sp. *Xiphinema* sp.	5–10		J. O. Becker	14.1	139.7
	(apricots) *Meloidogyne* sp. *Mesocriconema xenoplax* *Pratylenchus vulnus* *Xiphinema* sp.	5–10		M. McKenry	7.7	43.7
	(avocado) None			M. McKenry	25.3	232.4
	(citrus) *Tylenchulus semipenetrans*	1–5	R = 50	J. O. Becker	105.0	723.6
	(fig) *Meloidogyne* sp. *Xiphinema* sp.	20		J. D. Radewald		
	(grape) *Meloidogyne* sp. *Mesocriconema xenoplax* *Xiphinema index*	15–20		M. McKenry	267.0	1,713.4
	(kiwi) *Meloidogyne* sp.	20		M. McKenry	2.8	16.0
	(nectarine) *Meloidogyne* sp. *Mesocriconema xenoplax* *Pratylenchus* sp. *Xiphinema* sp.	10		M. McKenry	11.5	68.1
	(olive) *Meloidogyne* sp. *Tylenchulus semipenetrans*	5–10		M. McKenry	12.4	38.9
	(peach) *Mesocriconema xenoplax* *Pratylenchus* sp.	10		M. McKenry	24.4	165.3
	(pistachio) *Meloidogyne* sp. *Pratylenchus neglectus* *Xiphinema* sp.	1–5		M. McKenry	23.3	118.0

TABLE 16. *Continued*

State	(Crop)[a] Nematode	Loss (%)	Management (%)[b]	Source[c]	Hectares (thousands)[d]	Value (millions of dollars)[e]
	(plum)	5–10		M. McKenry	16.7	79.3
	Mesocriconema xenoplax					
	Pratylenchus sp.					
	(prune)	0–1		J. O. Becker	9.6	647.5
	Mesocriconema xenoplax					
	Pratylenchus sp.					
	(strawberry)	15–20		M. McKenry	76.5	238.9
	Pratylenchus sp.					
	(walnut)	20		J. D. Radewald	6.5	23.7
	Mesocriconema xenoplax					
	Pratylenchus vulnus					
CT	Unspecified	0–1		J. LaMondia	1.1	N/A
	Pratylenchus sp.					
	Xiphinema sp.					
	(strawberry)	1–5		J. LaMondia	0.2	N/A
	Meloidogyne hapla					
	Pratylenchus sp.					
FL	(citrus)	1–5		L. W. Duncan	347.0	1,610.9
	Pratylenchus coffeae		C = 100			
	Radopholus similis		R = 3, C = 100			
	Tylenchulus semipenetrans		R = 50, C = 100			
GA	(peach)	1–5	N = 8, T = 5, C = 30	R. F. Davis	9.7	27.6
	Meloidogyne sp.					
	Mesocriconema xenoplax					
HI	(banana)	10–15	N = 50	D. P. Schmitt, S. C. Nelson	0.4	5.0
	Meloidogyne sp.					
	Rotylenchulus reniformis					
	(citrus)	1–5	T = 5	B. S. Sipes	0.1	N/A
	Meloidogyne sp.					
	(coffee)	20–25	T = 5	D. P. Schmitt	1.8	12.0
	Meloidogyne sp.					
	Pratylenchus sp.					
	(guava)	1–5		D. P. Schmitt	1.9	2.1
	Meloidogyne sp.					
	Rotylenchulus reniformis					
	(macadamia)	0–1		D. P. Schmitt	7.5	36.2
	Unspecified					
	(papaya)	15–20		D. P. Schmitt	0.9	13.8
	Meloidogyne sp.					
	Rotylenchulus reniformis					
KY	(apple)	0–1		J. Hartman, J. Brown	0.7	N/A
	Meloidogyne sp.					
	(blueberry)	0		J. Hartman	0.1	N/A
	None					
	(brambles)	0–1		J. Hartman	0.1	N/A
	Xiphinema sp.					
	(grape)	0		J. Hartman	0.1	N/A
	Meloidogyne sp.					
	(peach)	0–1		J. Hartman, J. Brown	0.2	1.9
	Pratylenchus sp.					
	(strawberry)	0–1		J. Hartman	0.3	N/A
	Meloidogyne hapla					
	Pratylenchus sp.					
LA	(blueberry)	0–1		E. C. McGawley, C. Overstreet	0.2	2.4
	Unspecified					
	(citrus)	1–5	R = 100	E. C. McGawley, C. Overstreet	0.2	4.2
	Tylenchulus semipenetrans					
	(peach)		N = 80	E. C. McGawley, C. Overstreet	0.2	8.3
	Mesocriconema sp.					

TABLE 16. *Continued*

State	(Crop)[a] Nematode	Loss (%)	Management (%)[b]	Source[c]	Hectares (thousands)[d]	Value (millions of dollars)[e]
	(pecan) *Meloidogyne* sp.	5–10	0	E. C. McGawley, C. Overstreet	11.7	8.3
	(strawberry) *Meloidogyne hapla* *Pratylenchus* sp.	1–5	N = 50, T = 100	E. C. McGawley, C. Overstreet	0.5	7.2
MD	Unspecified *Pratylenchus penetrans* *Xiphinema* sp.	1–5		L. R. Krusberg	0.5	N/A
	(strawberry) *Meloidogyne hapla* *Pratylenchus penetrans*	1–5		L. R. Krusberg	0.3	N/A
MI	(apple) *Pratylenchus penetrans*	1–5		G. W. Bird, F. Warner	21.7	87.2
	(blueberry) None	0		G. W. Bird, F. Warner	5.3	26.1
	(cherry) *Meloidogyne hapla* *Pratylenchus penetrans* *Xiphinema americanum*	5–10		G. W. Bird, F. Warner	16.6	49.2
	(grape) *Meloidogyne hapla* *Meloidogyne nataliei*	5–10		G. W. Bird, F. Warner	4.5	15.5
	(peach) *Pratylenchus penetrans*	5–10		G. W. Bird, F. Warner	3.0	3.4
	(pear) *Pratylenchus penetrans*	1–5		G. W. Bird, F. Warner	0.5	1.3
	(strawberry) *Pratylenchus penetrans*	5–10		G. W. Bird, F. Warner	0.9	6.2
MS	(blueberry) Unspecified	0–1		J. Fox, F. Killebrew, M. Patel	0.1	N/A
	(grape-muscadine) Unspecified	0–1		J. Fox, F. Killebrew, M. Patel	0.3	N/A
	(peach) Unspecified	1–5		J. Fox, F. Killebrew, M. Patel	0.1	N/A
NC	(apple) *Pratylenchus* sp. *Xiphinema* sp.	0–1		S. Koenning	6.1	22.0
	(peach) *Meloidogyne incognita* *Mesocriconema xenoplax*	1–5		S. Koenning	1.6	7.2
PA	(apple) *Pratylenchus* sp. *Xiphinema* sp.	1–5		J. M. Halbrendt	9.8	41.6
	(cherry) *Pratylenchus* sp. *Xiphinema* sp.	5–10		J. M. Halbrendt	0.6	3.2
	(peach) *Xiphinema* sp.	5–10		J. M. Halbrendt	3.0	25.2
	(pear) None	0		J. M. Halbrendt	0.4	2.2
SC	(peach) *Mesocriconema xenoplax*	5–10		S. A. Lewis, T. Keinath, P. Dukes, C. E. Drye, O. J. Dickerson, T. A. Melton, P. Smith	9.7	35.7
TN	(apple) *Pratylenchus* sp.	0–1		S. Bost	0.7	1.8
TX	(citrus) *Tylenchulus semipenetrans*	5–10		T. Isakeit	8.9	33.2

TABLE 16. *Continued*

State	(Crop)[a] Nematode	Loss (%)	Management (%)[b]	Source[c]	Hectares (thousands)[d]	Value (millions of dollars)[e]
	(pecan)	3–5		T. A. Lee, G. Philley	N/A	48.8
	Meloidogyne sp.					
VA	(apple)	0–1		P. M. Phipps	9.3	26.9
	Hoplolaimus sp.					
	Mesocriconema sp.					
	Pratylenchus sp.					
WA	(apple)	5–10	N = 10	J. Wilson, G. S. Santo	60.7	756.8
	Pratylenchus penetrans					
	Xiphinema sp.					
	(blueberry)	1–5	0	G. S. Santo	0.6	4.2
	Pratylenchus penetrans					
	(cherry)	1–5	N = 5	J. Wilson, G. S. Santo	5.9	88.7
	Pratylenchus penetrans					
	Xiphinema sp.					
	(grape)	1–5	N = 5	J. Wilson, G. S. Santo	13.7	57.6
	Meloidogyne hapla					
	Mesocriconema xenoplax	1–5	0	G. S. Santo		
	Xiphinema pachtaicum					
	(peach)	1–5	0	G. S. Santo	1.0	9.0
	Pratylenchus penetrans					
	(pear)	1–5	0	G. S. Santo	9.6	97.4
	Pratylenchus penetrans					
	(raspberry)	1–5	N = 50	G. S. Santo	2.3	39.4
	Pratylenchus penetrans					
	(strawberry)	5–10	N = 40	G. S. Santo	0.6	5.5
	Pratylenchus penetrans					
U.S.					1,471	9,551

[a] Crops included are almond, apple, apricot, avocado, banana, blueberry, citrus, cherry, coffee, fig, grape, guava, macadamia, nectarine, papaya, peach, pear, pistachio, plum, prune, raspberry, and strawberry.

[b] The percentage of crop with one of the following management practices: R = resistant cultivars, N = nematicide, C = rootstock certification or resistance, and T = other.

[c] Source of information was personal communication.

[d] Anonymous (1995a). Hectarage of pecans is unavailable because of collections from wild trees. Production, however, was estimated at 97.4 million kg.

[e] Anonymous (1996). N/A = data not available.

even in older citrus regions (Ferguson et al., 1996).

Despite advances in integrated pest management and orchard management in nuts and fruit crops, plant-parasitic nematodes will continue to cause significant losses if current chemical options for sanitary use in preplant problem or disease-complex sites are legally restricted or banned. The increasing scarcity of suitable and affordable new land for tree orchards in major production areas guarantees that replant sites will be prone to increased nematode and replant disease problems.

Strawberry management differs considerably in production practices from the other fruit and nut crops because it is typically grown as an annual or biennial crop. In California, 90% of the land planted to strawberry is treated with a fumigant, and respondents from Florida indicate that methyl bromide is currently used on nearly 100% of the crop. The loss of methyl bromide is likely to effect large changes in production practices for this crop, in particular.

Golf greens: Respondents from 11 states provided information on losses in golf greens caused by phytoparasitic nematodes in 1994 (Table 17). Eleven states responded with estimates as high as 15%, although many states reported losses in the 0% to 1% range. Florida, Hawaii, Louisiana, and South Carolina all indicated losses in excess of 5% on golf greens. The species implicated most frequently included *B. longicaudatus, H. galeatus,* and *Paratrichodorus minor.* Damage to turf caused by plant-parasitic nematodes depends on the grass and nema-

TABLE 17. Estimated production losses in golf greens caused by plant-parasitic nematodes, reported species or genera, percent loss, percent of area receiving a given management tactic, source of information, and estimated area in crop in 1994.

State	(Crop) Nematode	Loss (%)	Management (%)[a]	Source[b]	Hectares (thousands)[c]
CA	Unspecified	1–2		J. O. Becker	N/A
CT	Unspecified	0–1		J. LaMondia	0.8
DE	*Hoplolaimus* sp.	0–1	N = 100	R. W. Taylor	N/A
FL	*Belonolaimus longicaudatus* *Hoplolaimus galeatus* *Paratrichodorus minor*	5–10		R. M. Giblin-Davis	60.3
		8–15	N = 50	R. A. Dunn	
GA	*Belonolaimus longicaudatus* *Hoplolaimus galeatus* *Meloidogyne* sp. *Mesocriconema ornatum*	1–5		R. F. Davis	N/A
HI	Unspecified	5–10	N = 75	S. C. Nelson, D. P. Schmitt	N/A
KY	Unspecified	0–1		P. Vincell	8.4
LA	*Belonolaimus longicaudatus*	5–10	N = 50	E. C. McGawley, C. Overstreet	0.2
NC	*Belonolaimus longicaudatus* *Paratrichodorus minor*	1–5		L. T. Lucas	25.5
NH	*Pratylenchus* sp.	1–5		C. Smith	2.0
SC	*Belonolaimus longicaudatus* *Hoplolaimus galeatus* *Mesocriconema ornatum* *Pratylenchus brachyurus*	5–10		O. J. Dickerson	19.0
TN	*Belonolaimus longicaudatus* *Hoplolaimus galeatus* *Paratrichodorus minor*	1–5		A. Windham	15.5

[a] The percentage of crop with one of the following management practices: R = resistant cultivars, N = nematicide, and T = other.
[b] Source of information was personal communication unless specified otherwise.
[c] Anonymous (1995a). N/A = data not available.

tode species involved as well as the management regime. Nematode damage is more severe when plants are stressed, but the aboveground symptoms of damage are often nondescript and the presence of plant-parasitic nematodes is frequently overlooked until plant death occurs. The most common method of reducing levels of plant-parasitic nematodes has been the use of nematicides (Blackburn et al., 1997). Respondents from five states indicated nematodes were controlled with nematicides on 50% to 100% of golf greens. Resistant cultivars and other means were not mentioned. Some effort also is directed at selection of resistant or tolerant cultivars (Giblin-Davis et al., 1995). Despite these efforts to manage plant-parasitic nematodes on turf, documentation of associated yield losses is not readily available.

Concluding remarks: Most extension specialists spend a considerable portion of their professional careers on the diagnosis and prevention of diseases caused by plant-parasitic nematodes, and are thus considered the authoritative sources of information used to compile the statistics presented in this publication. Often, it is their combined experiences and observations that serve as a foundation for estimation of damage potential of specific crop-nematode combinations. Clearly, some estimates should be identified as best guesses. In other instances, however, respondents have indicated the polling of as many county cooperative extension agents as possible to compile independent assessments of nematode-induced crop losses. In other cases, visual observations of root galling caused by species of *Meloidogyne* were used to construct nematode distribution estimates and assess crop loss (Barker et al., 1981). Although unsuitable for distributional analysis, nematode assay samples submitted to nematode diagnostic laboratories were also considered in the analysis of statewide distributions of nematodes and for crop-loss estimation (Imbriani, 1985). Formal geographic surveys have been conducted on nematode distribution, density, genetic diversity, and crop loss in some states or regions, and these data also add to our knowledge base. As a result, estimates for some crops probably reflect the situation more accurately than in previous estimations.

In most cases, the experts formulated estimates of crop loss based on reported and (or) visual summaries of the differences between plant yields attained between nematode-free and infested field portions. Field losses are then estimated after careful consideration of the incidence (frequency and geographic area) and severity of the nematode problem. Each field visit an expert makes provides another datum point characterizing the importance of nematodes as crop yield constraints. Yield losses on a state or regional basis are an integrated value derived from independent estimates of infested acreage, average infestation level, and an average or representative value for proportional yield loss (Noling, 1987). Thus, it is misleading to indicate that quantitative methods were not employed in the estimation process. Most contributors to this report have performed field and greenhouse cultivar screening trials, nematicide efficacy, and damage-function experiments. They are aware of the problems, pitfalls, and dangers associated with extrapolation. These same experts are also cognizant that many other physical, chemical, cultural, and biological factors can affect the nematode-crop relationship. The methods employed must, therefore, be considered both empirical and subjective in nature.

Most administrators, as well as many nematologists and plant pathologists, agree that estimates of nematode-induced crop losses are important in establishing funding and research priorities. Unfortunately, the funding to support the collection and publication of empirical data on crop losses is increasingly scarce. Another drawback is that the quantitative research required to develop more accurate assessments of crop loss are often considered to be of limited scientific value. Finally, the decline in the number of quantitatively oriented scientists within nematology limits the number of individuals contributing to the estimation process. The authors encountered considerable reticence among some state or university personnel to provide estimates. In some instances, individuals were either unwilling to devote the time required in order to respond or considered themselves unqualified to make an estimate. Some scientists were reluctant to provide estimates unless quantitative data were available to allow for verification.

The estimates included in this report cover a large number of crops but are by no means an exhaustive summary. Several categories that were not included were corn for silage, pastures, ornamentals, and forest plants. More concise estimates might be calculated if more categories for many crops, such as seed vs. grain, tobacco types, and fresh market vs. processed vegetables, were included. Nevertheless, the authors feel that this report provides valuable information.

LITERATURE CITED

Anonymous. 1995a. Acreage and acreage highlights. Washington, DC: National Agricultural Statistics Services.

Anonymous. 1995b. Vegetable annual summary and fresh market vegetables. Washington, DC: National Agricultural Statistics Service.

Anonymous. 1996. Agricultural Statistics 1995–96. Washington, DC: National Agricultural Statistics Service, U.S. Department of Agriculture.

Anonymous. 1997. Crop values 1996 summary. Washington, DC: National Agricultural Statistics Service.

Anzalone, L., and W. Birchfield. 1977. Varietal resistance in sugarcane to *Meloidogyne incognita*. Plant Disease Reporter 61:190–191.

Armstrong, J. S., F. B. Peairs, S. D. Pilcher, and C. C. Russell. 1993. The effect of planting time, insecticides, and liquid fertilizers on the Russian wheat aphid (Homoptera: Aphididae) and the lesion nematode (*Pratylenchus thornei*) on winter wheat. Journal of the Kansas Entomological Society 66:69–74.

Arnett, J. D. 1984. Tobacco-disease loss estimates. 1984. Tobacco Disease Loss Evaluation Committee Report, College of Agriculture, University of Georgia, Athens, GA.

Atkins, J. G., and M. A. Marchetti. 1979. Rice diseases. Farmers Bulletin No. 2120. Washington, D.C.: U.S. Department of Agriculture.

Baird, R. E., R. F. Davis, P. J. Alt, B. G. Mullinix, and G. B. Padgett. 1996. Frequency and geographical distribution of plant-parasitic nematodes in Georgia. Supplement to the Journal of Nematology 28:661–667.

Barker, K. R. 1989. Yield relationships and population dynamics of *Meloidogyne* spp. on flue-cured tobacco. Supplement to the Journal of Nematology 21: 597–603.

Barker, K. R., and S. R. Koenning. 1997. Interactions of *Meloidogyne incognita* populations with selected cotton cultivars. Journal of Nematology 29:569 (Abstr.).

Barker, K. R., S. R. Koenning, A. L. Bostian, and A. R. Ayers. 1988. Growth and yield responses of soybean to aldicarb. Journal of Nematology 20:421–432.

Barker, K. R., F. A. Todd, and W. W. Shane. 1981. Interrelationships of *Meloidogyne* species with flue-cured tobacco. Journal of Nematology 13:67–78.

Bertrand, P. F. 1995. 1994 Georgia plant disease loss estimates. Tifton, GA: University of Georgia Cooperative Extension Service.

Birchfield, W. 1984. Nematode parasites of sugarcane. Pp. 571–588 *In* W. R. Nickle, ed. Plant and insect nematodes. New York, NY: Marcel Dekker.

Bird, G. W., and L. S. Graney. 1986. The hidden enemy. Michigan Cooperative Extension Service Bulletin E-701.

Blackburn, K., S. R. Alm, T. S. Yek, and C. G. Dawson. 1997. High-pressure liquid injection of isazofos for management of *Hoplolaimus galeatus* and *Tylenchorhynchus dubius* infesting turfgrasses. Supplement to the Journal of Nematology 29:690–694.

Blasingame, D. 1993. Nematode distribution and density. Pp. 4–6 *in* Cotton nematodes — your hidden enemies. Beltwide Cotton Nematode Survey and Education Committee. Research Triangle Park, NC: Rhone-Poulenc.

Blasingame, D. J. 1995. Cotton disease estimate committee report. P. 195 *in* Proceedings, Beltwide Cotton Conference.

Brown, D. J. F., J. M. Halbrendt, R. T. Robbins, and T. C. Vrain. 1993. Transmission of nepoviruses by *Xiphinema americanum*-group nematodes. Journal of Nematology 25:349–354.

Cook, C. G., A. F. Robinson, and L. N. Namken. 1997. Tolerance to *Rotylenchulus reniformis* and resistance to *Meloidogyne incognita* race 3 in high-yielding breeding lines of upland cotton. Journal of Nematology 29:322–328.

Dickson, D. W. 1998. Peanut. Pp. 523–566 *in* K. R. Barker, G. A. Pederson, and G. L. Windham, eds. Plant and nematode interactions. Madison, WI: American Society of Agronomy, Crop Science Society of America, Soil Science Society of America.

Doupnik, B., Jr. 1993. Soybean production and disease loss estimates for North Central United States from 1989–1991. Plant Disease 77:1170–1171.

Duncan, L. W., and J. W. Noling. 1998. Agricultural sustainability and nematode integrated pest management. Pp. 251–287 *in* K. R. Barker, G. A. Pederson, and G. L. Windham, eds. Plant and nematode interactions. Madison, WI: American Society of Agronomy, Crop Science Society of America, Soil Science Society of America.

Feldmesser, J., Chairman. 1971. Estimated crop losses from plant-parasitic nematodes in the United States. Society of Nematologists Special Publication No. 1. Hyattsville, MD: Society of Nematologists.

Ferguson, J. J., L. W. Duncan, and D. E. Norden. 1996. Occurrence of the citrus nematode in old citrus-growing regions of Florida. Soil and Crop Science Society of Florida Proceedings 55:5–8.

Ferris, H., and J. W. Noling. 1987. Analysis and prediction as a basis for management decisions. Pp. 49–56 *in* R. H. Brown and B. R. Kerry, eds. Principles and practice of nematode control in crops. New York: Academic Press.

Fortnum, B. A., and R. E. Currin, III. 1988. Host suitability of grain sorghum cultivars to *Meloidogyne* spp. Annals of Applied Nematology (Journal of Nematology 20, Supplement) 2:61–64.

Fortnum, B. A., J. P. Krausz, and N. Conrad. 1984. Increasing incidence of *Meloidogyne arenaria* on flue-cured tobacco in South Carolina. Plant Disease 68:244–245.

Francl, L. J., and V. H. Dropkin. 1986. *Heterodera glycines* population dynamics and relation of initial population to soybean yield. Plant Disease 70:791–795.

Giblin-Davis, R. M., P. Busey, and B. J. Center. 1995. Parasitism of *Hoplolaimus galeatus* on diploid and polyploid St. Augustine grasses. Journal of Nematology 27: 472–477.

Gooden, D. T., G. D. Christenbury, B. A. Fortnum, D. G. Manley, E. Murdock, and R. W. Sutton. 1998. South Carolina tobacco grower's guide—1999. South Carolina Cooperative Extension Circular EC 569.

Gooden, D. T., G. D. Christenbury, M. I. Loyd, D. G. Manley, S. B. Martin, and L. A. Stanton. 1991. South Carolina tobacco grower's guide—1990. South Carolina Cooperative Extension Circular EC 569.

Gooden, D. T., J. W. Rideout, G. D. Christenbury, M. I. Loyd, D. G. Manley, S. B. Martin, and L. A. Stanton. 1994. South Carolina tobacco grower's guide—1994. South Carolina Cooperative Extension Circular EC 569.

Griffin, G. D. 1993. Influence of temperature on the virulence of two races of *Meloidogyne chitwoodi* on wheat and barley. Journal of Nematology 25:454–460.

Griffin, G. D. 1998. Alfalfa. Pp. 381–387 *in* K. R. Barker, G. L. Pederson, and G. A. Windham, eds. Plant and nematode interactions. Madison, WI: American Society of Agronomy, Crop Science Society of America, Soil Science Society of America.

Heald, C. M., and A. F. Robinson. 1990. Survey of current distribution of *Rotylenchulus* in the United States. Supplement to the Journal of Nematology 22: 695–699.

Hollis, J. P., and S. Keoboonrueng. 1984. Nematode parasites of rice. Pp. 95–146 *in* W. R. Nickle, ed. Plant and insect nematodes. New York: Marcel Dekker.

Ibrahim, I. K. A., S. A. Lewis, and D. C. Harshman. 1993. Host suitability of graminaceous crop cultivars for isolates of *Meloidogyne arenaria* and *M. incognita*. Journal of Nematology 25:858–862.

Imbriani, J. L. 1985. The practical application of a nematode advisory service. Pp. 309–323 *in* J. N. Sasser and C. C. Carter, eds. An advance treatise on *Meloidogyne,* vol. I. Biology and control. Raleigh, NC: North Carolina State University Graphics.

Israel, G. D. 1998. Using focus group interviews for evaluating extension programs. Gainesville, FL: Florida Cooperative Extension Service, Institute of Food and Agricultural Sciences, University of Florida.

Kinloch, R. A., and R. K. Sprenkel. 1994. Plant-parasitic nematodes associated with cotton in Florida. Supplement to the Journal of Nematology 26:749–752.

Kittrell, B. U., G. D. Christenbury, J. P. Krausz, M. I. Loyd, D. G. Manley, and L. A. Stanton. 1989. South Carolina tobacco grower's guide—1988. South Carolina Cooperative Extension Circular EC 569.

Koenning, S. R., and K. R. Barker. 1998. Survey of *Heterodera glycines* races and other plant-parasitic nematodes in soybean in North Carolina. Supplement to the Journal of Nematology 30:569–576.

Koenning, S. R., D. P. Schmitt, and K. R. Barker. 1993. Effects of cropping systems on population densities of *Heterodera glycines* and soybean yield. Plant Disease 77:780–786.

Koenning, S. R., S. A. Walters, and K. R. Barker. 1996. Impact of soil texture on the reproductive and damage potential of *Rotylenchulus reniformis* and *Meloidogyne incognita* on cotton. Journal of Nematology 28:527–536.

LaMondia, J. A. 1995. Shade tobacco yield loss and *Globodera tabacum tabacum* population changes in relation to initial nematode density. Journal of Nematology 27:114–119.

Lewis, S. A., C. E. Drye, J. A. Saunders, E. R. Shipe, and J. M. Halbrendt. 1993. Plant-parasitic nematodes on soybean in South Carolina. Supplement to the Journal of Nematology 25:890–894.

MacGuidwin, A. E., C. R. Grau, and E. S. Oplinger. 1995. Impact of planting 'Bell', a soybean cultivar resistant to *Heterodera glycines,* in Wisconsin. Journal of Nematology 27:78–85.

Main, C. E., and S. V. Byrne, eds. 1986. 1985 estimates of crop losses in North Carolina due to plant diseases and nematodes. Department of Plant Pathology Special Publication No. 5, North Carolina State University, Raleigh, NC.

Main, C. E., and S. M. Nusser, eds. 1985. 1984 estimates of crop losses in North Carolina due to plant diseases and nematodes. Department of Plant Pathology Special Publication No. 4, North Carolina State University, Raleigh, NC.

Martin, S. B., J. D. Mueller, J. A. Saunders, and W. I. Jones. 1994. A survey of South Carolina cotton fields for plant-parasitic nematodes. Plants Disease 78:717–719.

McGawley, E. C., and C. Overstreet. 1998. Rice and other cereals. Pp. 455–486 *in* K. R. Barker, G. A. Pederson, and G. L. Windham, eds. Plant and nematode interactions. Madison, WI: American Society of Agronomy, Crop Science Society of America, Soil Science Society of America.

McGawley, E. C., M. C. Rush, and J. P. Hollis. 1984. Occurrence of *Aphelenchoides besseyi* in Louisiana rice seed and its interaction with *Sclerotium oryzae* in selected cultivars. Journal of Nematology 16:65–68.

McGawley, E. C., J. W. Hoy, C. Overstreet, J. P. Bond, and M. J. Pontif. 1997. Nematology research. Pp. 126–129 *in* Sugarcane research, annual progress report, 1997. Louisiana Agricultural Experiment Station Publication, Baton Rouge, LA.

McSorley, R., and R. N. Gallaher. 1991. Nematode population changes and forage yields of six corn and sorghum cultivars. Journal of Nematology 23:673–677.

Melton, T. A., D. Porter, and A. Broadwell. 1998. Extension-research flue-cured tobacco pathology program annual report. Raleigh, NC: North Carolina Cooperative Extension Service.

Melton, T. A., D. Porter, and A. Broadwell. 1999. Disease management. Pp. 89–114 *in* Flue-cured tobacco information, AG187. Raleigh, NC: North Carolina Cooperative Extension Service.

Miller, R. W. 1994. Estimated peach tree losses 1980 to 1992 in South Carolina: Causes and economic impact. Pp. 121–127 *in* A. P. Nyczepir, P. F. Bertrand, and T. G. Beckman, eds. Proceedings of the 6th Stone Fruit Decline Workshop, Fort Valley, GA. Publication ARS-122. Springfield, VA: USDA Agricultural Research Service, National Technical Information Service.

Mojtahedi, H., G. S. Santo, and J. M. Kraft. 1992. *Pratylenchus neglectus* on dryland wheat in Washington. Plant Disease 76:323.

Niblack, T. L., R. D. Heinz, G. S. Smith, and P. A. Donald. 1993. Distribution, density, and diversity of *Heterodera glycines* in Missouri. Supplement to the Journal of Nematology 25:880–886.

Noling, J. W. 1987. Partitioning crop losses. Pp. 64-74 *in* J. A. Veech and D. W. Dickson, eds. Vistas on nematology. Hyattsville, MD: Society of Nematologists.

Noling, J. W., and J. O. Becker. 1994. The challenge of research and extension to define and implement alternatives to methyl bromide. Supplement to the Journal of Nematology 26:573–586.

Noling, J. W., and H. Ferris. 1987. Nematode-degree days, a density-time model for relating epidemiology and crop losses in perennials. Journal of Nematology 19:108–118.

Nyczepir, A. P., and J. O. Becker. 1998. Fruit and citrus trees. Pp. 637–684 *in* K. R. Barker, G. A. Pederson, and G. L. Windham, eds. Plant and nematode interactions. Madison, WI: American Society of Agronomy, Crop Science Society of America, Soil Science Society of America.

Ogallo, J. L., P. B. Goodell, J. Eckert, and P. A. Roberts. 1997. Evaluation of NemX, a new cultivar of cotton with high resistance to *Meloidogyne incognita.* Journal of Nematology 29:531–537.

Patton, M. Q. 1982. The logic of survey analysis and practical evaluation. Beverly Hills, CA: Sage Publications.

Pike, D. R., K. L. Steffey, M. E. Gray, H. W. Kirby, D. I. Edwards, and R. H. Hornbaker. 1995. Biologic and economic assessment of pesticide use on corn and soybeans. Report Number 1-CA-95. Washington, DC: National Agricultural Pesticide Impact Assessment Program.

Popova, M. B., G. L. Zelenskii, and S. A. Subbotin. 1994. An assessment of resistance in cultivars of *Oryza sativa* L. to *Aphelenchoides besseyi* Christie, 1942. Russian Journal of Nematology 2:41–44.

Ristaino, J. B., and W. Thomas. 1997. Agriculture, methyl bromide, and the ozone hole—can we fill the gaps? Plant Disease 81:964–977.

Robbins, R. T., R. D. Riggs, and D. Von Steen. 1989. Phytoparasitic nematode surveys of Arkansas cotton fields, 1986–1988. Supplement to the Journal of Nematology 21:619–623.

Sasser, J. N., and D. W. Freckman. 1987. A world perspective on nematology: The role of the society. Pp. 7–14 *in* J. A. Veech and D. W. Dickson, eds. Vistas on nematology. Hyattsville, MD: Society of Nematologists.

Schmitt, D. P., H. Ferris, and K. R. Barker. 1987. Response of soybean to *Heteroderea glycines* races 1 and 2 in different soil types. Journal of Nematology 19:240–250.

Schneider, S. M. 1991. Nematode diseases. Pp. 37–40 *in* G. Lucas and H. D. Shew, eds. Compendium of tobacco diseases. St. Paul, MN: APS Press.

Sikora, E. J., and G. R. Noel. 1991. Distribution of *Heterodera glycines* races in Illinois. Supplement to the Journal of Nematology 23:624–628.

Smiley, R. W., R. E. Ingham, W. Uddin, and G. H. Cook. 1994. Crop sequences for managing cereal cyst nematode and fungal pathogens of winter wheat. Plant Disease 78:1142–1149.

Society of Nematologists Crop Loss Assessment Committee. 1987. Bibliography of estimated crop losses in the United States due to plant-parasitic nematodes. Annals of Applied Nematology (Journal of Nematology 19, Supplement) 1:6–12.

Spaull, V. W., and P. Cadet. 1990. Nematode parasites of sugarcane. Pp. 461–491 *in* M. Luc, R. A. Sikora, and J. Bridge, eds. Plant-parasitic nematodes in subtropical and tropical agriculture. Wallingford, UK: CAB International.

Spreen, T. H., J. J. Van Sickle, A. E. Moseley, M. S. Deepak, and L. Mathers. 1995. Use of methyl bromide and economic impact of its proposed ban on Florida fresh market fruit and vegetable industry. University of Florida Experiment Station Bulletin No. 898.

Starr, J. L. 1992. Nematode pathogens of sorghum. Pp. 179–185 *in* W. A. C. de Milliano, R. A. Fredericksen, and G. D. Bengston, eds. Sorghum and millet diseases: A second world review. Patancheru, India: International Crops Research Institute for the Semi-Arid Tropics.

Starr, J. L. 1998. Cotton. Pp. 359–380 *in* K. R. Barker, G. A. Pederson, and G. L. Windham, eds. Plant and nematode interactions. Madison, WI: American Society of Agronomy, Crop Science Society of America, Soil Science Society of America.

Sturgeon, R. V., Jr. 1984. Peanut disease loss estimates for major peanut-producing states in the United States for 1983. Proceedings of the American Peanut Research and Education Society 16:62–64.

Swarup, G., and C. Sosa-Moss. 1990. Nematode parasites of cereals. Pp. 109–136 *in* M. Luc, R. A. Sikora, and J. Bridge, eds. Plant-parasitic nematodes in subtropical and tropical agriculture. Wallingford, UK: CAB International.

Teng, P. S. 1985. Crop loss assessment methods: Current situation and needs. Pp. 149–158 *in* K. R. Barker, C. C. Carter, and J. N. Sasser, eds. An advanced treatise on *Meloidogyne*. Volume II, Methodology. Raleigh, NC: North Carolina State University Graphics.

Teng, P. S. 1987. Crop loss assessment and pest management. St. Paul, MN: APS Press.

Thies, J. A., D. K. Barnes, D. L. Rabas, C. C. Sheaffer, and R. D. Wilcoxson. 1992. Seeding date, carbofuran, and resistance to root-lesion nematode affect alfalfa-stand establishment. Crop Science 32:786–792.

Thomas, W. B. 1996. Methyl bromide: Effective pest management tool and environmental threat. Supplement to the Journal of Nematology 28:586–589.

Todd, T. C., W. T. Schapaugh, Jr., J. H. Long, and B. Holmes. 1995. Field response of soybean in maturity groups III-V to *Heterodera glycines* in Kansas. Journal of Nematology 27:628–633.

Townshend, J. L. 1989. Efficacy of oxamyl coated on alfalfa seed with a polymer sticker in *Pratylenchus*- and *Meloidogyne*-infested soils. Journal of Nematology 21: 242–246.

United Nations Environment Programme. 1995. Report of the methyl bromide technical options committee. Montreal protocol on substances that deplete the ozone layer. Washington, DC: United Nations.

U.S. Department of Agriculture. 1985a. Pesticide assessment of field corn and soybeans: Lake states. ERS Staff Report No. AGES850524C, National Agricultural Pesticide Impact Assessment Program. Washington, DC: U.S. Department of Agriculture.

U.S. Department of Agriculture. 1985b. Pesticide assessment of field corn and soybeans: Southeastern states. ERS Staff Report No. AGES850524F, National Agricultural Pesticide Impact Assessment Program. Washington, DC: U.S. Department of Agriculture.

U.S. Department of Agriculture. 1985c. Pesticide assessment of field corn and soybeans: Northeastern states. ERS Staff Report No. AGES850524D, National Agricultural Pesticide Impact Assessment Program. Washington, DC: U.S. Department of Agriculture.

U.S. Department of Agriculture. 1985d. Pesticide assessment of field corn and soybeans: Cornbelt states. ERS Staff Report No. AGES850524A, National Agricultural Pesticide Impact Assessment Program. Washington, DC: U.S. Department of Agriculture.

U.S. Department of Agriculture. 1985e. Pesticide assessment of field corn and soybeans: Delta states. ERS Staff Report No. AGES850524B, National Agricultural Pesticide Impact Assessment Program. Washington, DC: U.S. Department of Agriculture.

U.S. Department of Agriculture. 1993. The biologic and economic assessment of methyl bromide. Washington, DC: National Agricultural Pesticide Impact Assessment Program.

U.S. Environmental Protection Agency. 1993. 40CFR Part 82. Protection of stratospheric ozone: Final rule making. Federal Register. Washington, DC: United States Government.

Warner, F., R. Mather, G. Bird, and J. Davenport. 1994. Nematodes in Michigan. I. Distribution of *Heterodera glycines* and other plant-parasitic nematodes in soybean. Supplement to the Journal of Nematology 26: 720–726.

Wheeler, T. A., P. E. Pierson, C. E. Young, R. M. Riedel, H. R. Wilson, J. B. Eisley, A. F. Schmitthenner, and P. E. Lipps. 1997. Effect of soybean cyst nematode *Heterodera glycines* on resistant and susceptible soybean cultivars grown in Ohio. Supplement to the Journal of Nematology 29:703–709.

Williams, J. R. 1969. Nematodes attacking sugarcane. Pp. 204–209 *in* J. E. Peachey, ed. Nematodes of tropical crops. Harpenden, UK: Commonwealth Agricultural Bureaux.

Willis, C. B., and L. S. Thompson. 1979. Effects of phenamiphos, methyl bromide, and fallowing on *Pratylenchus penetrans,* yield of *Medicago sativa,* and *Fusarium* infections. Journal of Nematology 11:265–269.

Willson, H. R., R. M. Riedel, J. B. Eisley, C. E. Young, J. R. Josinski, T. A. Wheeler, P. H. Kauffman, P. E. Pierson, and M. C. Stuart. 1996. Distribution of *Heterodera glycines* in Ohio. Supplement to the Journal of Nematology 28:599–603.

Windham, G. L. 1998. Corn. Pp. 335–357 *in* K. R. Barker, G. A. Pederson, and G. L. Windham, eds. Plant-nematode interactions. Madison, WI: American Society of Agronomy, Crop Science Society of America, Soil Science Society of America.

Workneh, F., G. L. Tylka, X. B. Yang, J. Faghihi, and J. M. Ferris. 1999. Regional assessment of soybean brown stem rot, *Phytophthora sojae,* and *Heterodera glycines* using area-frame sampling: Prevalence and effects of tillage. Phytopathology 89:204–211.

Wrather, J. A. 1995. Soybean disease loss estimated for the southern United States during 1994. Pp. 1–6 *in* February 22–24, 1995 Proceedings of the Southern Soybean Disease Workers Twenty-Second Annual Meeting, St. Louis, MO.

Wrather, J. A., T. R. Anderson, D. M. Arzsad, J. Gai, L. D. Ploper, A. Porta-Puglia, H. H. Ram, and Y. T. Yorinori. 1997. Soybean disease loss estimates for the top 10 soybean-producing countries in 1995. Plant Disease 81;107–110.

Wrather, J. A., A. Y. Chambers, J. A. Fox, W. F. Moore, and G. L. Sciumbato. 1995. Soybean disease estimates for the southern United States, 1974 to 1994. Plant Disease 79:1076–1079.

Wrather, J. A., T. L. Niblack, and M. R. Milan. 1992. Survey of plant-parasitic nematodes in Missouri cotton fields. Journal of Nematology 24:779–782.

Young, L. D. 1990. Survey of soybean cyst nematode races in Tennessee. Supplement to the Journal of Nematology 22:672–675.

Young, L. D. 1996. Yield loss in soybean caused by *Heterodera glycines.* Supplement to the Journal of Nematology 28:604–607.

Young, L. D. 1998. Breeding for nematode resistance. Pp. 187–207 *in* K. R. Barker, G. A. Pederson, and G. L. Windham, eds. Plant and nematode interactions. Madison, WI: American Society of Agronomy, Crop Science Society of America, Soil Science Society of America.