Cost Effectiveness of Pest Management Strategies in Peanut (*Arachis hypogaea* L.) Grown in North Carolina

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ABSTRACT

Reducing costs associated with pest management in peanut (*Arachis hypogaea* L.) production systems in the United States will become increasingly important due to changes in federal legislation that reduced support prices and removed the escalator provision. The federal peanut program may be eliminated completely in 2002 at which time peanut most likely will be marketed at the world price, which is substantially lower than the current quota price. Eight experiments were conducted during 1997 and 1998 to evaluate pest control, pod yield, gross value, and economic return with preventive and integrated pest management (IPM)-based disease, insect, and weed management strategies. Preventive strategies included prophylactic applications of herbicides, fungicides, fumigant, and insecticides. IPM strategies involved host-plant resistance, targeting pesticide applications based on economic thresholds, and other threshold-based practices to manage pests. Preventive and IPM weed management strategies provided similar economic return in seven of eight experiments. Early leaf spot, caused by *Cercospora arachidicola*, control was similar when fungicides were applied biweekly or based on weather advisories. However, scheduling fungicide sprays using weather-based advisories eliminated one to three fungicide applications per year. Biweekly applications of fungicides increased damage from twospotted spider mite (*Tetranycychus urticae*) in one experiment compared with applications using weather-based advisories. Fumigation by metam sodium for Cylindrocladium black rot (CBR), caused by *Cylindrocladium crotalarie*, was needed in one of three experiments where this disease was present. Resistance of the cultivar NC 12C to CBR was not sufficient to prevent yield and economic loss where damage exceeded 10% plant loss. Iprodione was applied preventatively for suppression of Sclerotinia blight, caused by *Sclerotinia minor*. However, this disease developed in only one of four experiments where fungicide was applied. Aldicarb applied in-furrow and acephate applied postemergence based on damage thresholds controlled tobacco thrips (*Frankliniella fusca*) similarly in seven of eight experiments. In one experiment, aldicarb was more effective than acephate. Failure to apply chlorpyrifos for southern corn rootworm (*Diabrotica undecimpunctata*) control resulted in yield and economic loss in three experiments. Chlorpyrifos controlled potato leafhopper (*Empoasca fabae*) and prevented possible yield loss caused by this insect. Collectively, these data demonstrate the complexity of pest management in peanut and some of the weaknesses associated with current pest control and IPM practices. The importance of accurate identification of pests and detailed field histories also was demonstrated in these studies. Likewise, a thorough understanding of the impact of production practices on pest development and timely implementation of pest control tactics is critical for adequate plant protection.

Key Words: Disease management, economic analyses, insect management, integrated pest management, IPM, preventive pest management, weather-based advisory, weed management.

Prior to farm legislation enacted in 1996, the federal peanut program provided a price support of 0.67 $/kg for farmer stock, quota peanut (Brown, 1998). This price was adjusted annually by an escalator provision that increased the price support in proportion to increases in production costs (Brown, 1998). However, federal legislation in 1996 decreased the price support by approximately 10% and removed the escalator provision (Brown, 1998). These changes have decreased the economic value of peanut at the farm level and have increased the need to re-evaluate the cost effectiveness of pest management and other production practices. Public anxiety associated with the effect of pesticide use on food quality and the environment also has led to closer scrutiny of production practices. Management of diseases, insects, and weeds are three major costs in peanut production (Lynch and Mack, 1995; Sherwood *et al.*, 1995; Wilcut *et al.*, 1995). Cost of managing these pests is approximately 33% of total annual operating costs in North Carolina (Brown, 1998).

The three major insect pests of peanut are tobacco thrips (*Frankliniella fusca* Hinds), southern corn rootworm (*Diabrotica undecimpunctata* Howardi), and twospotted spider mite (*Tetranycychus urticae* Koch). Peanut growers in North Carolina spend approximately 9% of total operating costs on insect management (Brown, 1998). Based on a 1995 survey conducted by the North Carolina Coop. Ext. Serv., aldicarb [2-methyl-2-(methylthio)propionaldehyde] was applied in-furrow on 65% of hectares (Toth, 1998). Based on the same survey, acephate (*O*,*S*-dimethylacetylphosphoramidothioate) was applied to seedling peanut on approximately 11% of hectares. These insecticides control tobacco thrips (Lynch and Mack, 1995; Brandenburg, 1998). Approximately 30% of peanut hectares were treated with pesticides to control foliar insects such as corn earworm [*Helicoverpa*

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zea (Boddie)] and 21% were treated for twospotted spider mite. Peanut growers applied chlorpyrifos [*O*,*O*-diethyl *O*-(3,5,6-trichloro-2-pyridinyl)phosphorothioate] or fonofos (*O*-ethyl-*S*-phenylethylphosphonodithioate) on approximately 56 and 8% of peanut hectares, respectively, to control the southern corn rootworm in North Carolina (Toth, 1998). Although chlorpyrifos controls southern corn rootworm, use can exacerbate twospotted spider mite infestations (Brandenburg, 1998). Additionally, the economic benefits of southern corn rootworm control are questionable under certain environmental and edaphic conditions (Herbert *et al.*, 1997). A risk index has been developed to predict when damage from southern corn rootworm will occur, which will help minimize unnecessary insecticide applications (Herbert *et al.*, 1997).

Major diseases of peanut grown in North Carolina are early leaf spot (caused by *Cercospora arachidicola* Hori), CBR [caused by *Cylindrocladium crotalarie* (Loos) Bell and Sobers], Sclerotinia blight (caused by *Sclerotinia minor* Jagger), rhizoctonia limb and pod rot (caused by *Rhizoctonia solani* Kuhn), and southern stem rot (caused by *Sclerotium rolfsii* Sacc.) (Bailey and Shew, 1998). Tomato spotted wilt virus (TSWV) also negatively impacts peanut production in North Carolina (Bailey and Shew, 1998). Peanut growers in North Carolina spend approximately 14% of total operating costs on fumigants and fungicides to manage diseases (Brown, 1998). Expenditures vary considerably from year to year because of fluctuations in weather. Fungicides are relatively effective in controlling most diseases except Sclerotinia blight (Bailey and Shew, 1998). Fumigation with metam sodium controls CBR in most situations but must be applied preventively. Improved host-plant resistance is currently being developed to Sclerotinia blight, CBR, nematodes, and leaf spots (Sherwood *et al.*, 1995). However, the level of resistance found in commercially acceptable cultivars is not sufficient to prevent economic loss from these pests. Long rotations of non-host crops also reduce disease severity; however, pesticides are critical in maintaining yield in most fields.

Peanut growers spend approximately 10% of total annual operating costs on weed management (Brown, 1998). Ninety-eight percent of growers applied herbicides to North Carolina peanut fields in 1995 (Toth, 1998). The poor competitive nature of peanut combined with the requirement to dig plants for harvest necessitate effective season-long control of many species to prevent yield loss (Wilcut *et al.*, 1995). In North Carolina, the most troublesome weeds include purple nutsedge (*Cyperus rotundus* L.), yellow nutsedge (*C. esculentas* L.), eclipta (*Eclipta prostrata* L.), common ragweed (*Ambrosia artemisiifolia* L), prickly sida (*Sida spinosa* L.), and sicklepod [*Senna obtusifolia* (L.) Irwin and Barneby] (Dowler, 1998). Crop rotation, establishing a competitive crop, and cultivation are important components of weed management systems in peanut (Wilcut *et al.*, 1995; Jordan and York, 1999). A variety of herbicides are available to control weeds in peanut fields, although herbicide programs can be expensive (Wilcut *et al.*, 1995; Jordan and York, 1999). Many herbicides are applied to soil before planting or following planting but before weeds emerge (Wilcut *et al.*, 1995). For example, approximately 45% of peanut hectares in North Carolina were treated with pendimethalin [*N*-(1-ethylpropyl)-3,4-dimethyl-2,6-dinitrobenzenamine] or vernolate (*S*-propyl dipropylcarbamothioate) before planting, and as many as 70% of hectares were treated with metolachlor [2-chloro-*N*-(2-ethyl-6-methylphenyl)-*N*-(2-methoxy-1-methyl-ethyl)acetamide] prior to peanut emergence (Toth, 1998). These herbicides generally are applied based on field history of specific weed complexes. Postemergence herbicides are often needed to control weeds season-long (Wilcut *et al.*, 1995).

Economic threshold data for specific weed populations can be used in computer models to determine when herbicide use is economically justified (White and Coble, 1997; MacDonald *et al.*, 1998; Wilcut *et al.*, 1999). The PEANUT HERB model has been successful in using the density of each weed species, projected yield loss, control cost, and yield and economic value to rank herbicide options (MacDonald *et al.*, 1998; Wilcut *et al.*, 1999).

Integrated pest management (IPM) strategies can reduce pest management costs in peanut in North Carolina by $50 to $125/ha (Mueller and Linker, 1999). Use of weather-based advisories to schedule fungicide sprays, economic thresholds for insecticide sprays, extending crop rotations to break pest cycles, cultivation to manage weeds, and planting disease and insect resistant cultivars to minimize yield loss are important components of IPM in peanut (Lynch and Mack, 1995; Sherwood *et al.*, 1995; Wilcut *et al.*, 1995; Mueller and Linker, 1999). However, in the survey by Toth (1998), only 53% of peanut growers in North Carolina indicated that they practiced IPM, although 87% of respondents indicated that IPM is a good approach. Perceived risk of IPM rather than prophylactic treatments and a limited labor pool needed to implement IPM were listed as reasons limiting adoption (Toth, 1998). Yet many of these growers are adjusting pesticide sprays according to field history and weather. A better understanding of the complexities and interactions among pests, pest control tactics, and production systems should lead to more efficient pest management and reduced risk associated with IPM.

Because of changes in federal legislation reducing farm value of peanut, there is increased need to develop and implement pest management strategies that are less expensive while maintaining high yield and quality. Practices that have fewer negative environmental and social impacts also would be beneficial. Research was conducted in 1997 and 1998 to evaluate interactions among IPM and preventive pest strategies for diseases, insects, and weeds in peanut grown in North Carolina.

Materials and Methods

Field Sites. The experiments were conducted during the 1997 and 1998 growing seasons at the Peanut Belt Res. Sta. near Lewiston, NC, at the Upper Coastal Plain Res. Sta. near Rocky Mount, NC, and on a private farm near Tyner, NC. The experiment also was conducted on private farms near Windsor, NC in 1997 and Bladenboro, NC in 1998.

Soil at Lewiston and Bladenboro was a Norfolk sandy loam (fine-loamy, siliceous, thermic Aquic Paleudults). A Goldsboro sandy loam soil (fine-loamy, siliceous, thermic Aquic Paleudalts) was at Rocky Mount. Soil was a Conetoe loamy sand (fine-loamy, mixed, thermic, Arenic Hapludults) at Windsor and Tyner. Peanut was planted in conventionally tilled fields on beds. Fields were disked and rows established using a ripper/bedder. Plot size was four rows (90-cm spacing) by 15 m.

Cultivars. The cultivar NC 12C was planted at Lewiston, Bladenboro, Tyner, and Windsor. The cultivar GK 7 was planted at Rocky Mount. NC 12C is a commercially acceptable virginia-market type with partial resistance to CBR and moderate susceptibility to early leaf spot (Bailey and Shew, 1998). This cultivar is very susceptible to Sclerotinia blight (Bailey and Shew, 1998). GK 7 is a runner-market type grown primarily in the southeastern and southwestern U.S and is susceptible to major diseases in peanut (Smith and Simpson, 1995). Commercially treated seed of NC 12C was planted at 110 kg/ha and GK 7 was planted at 80 kg/ha. Peanut was planted the 1st wk of May at Windsor and Rocky Mount in 1997 and at Lewiston and Tyner in both years. Peanut was planted in mid-May in 1998 at Rocky Mount and at Bladenboro.

Preventive Strategy. Treatments consisted of a factorial arrangement of two levels of pest management (IPM and preventive) for diseases, insects, and weeds. The insect preventive strategy was composed of aldicarb applied in-furrow at 1.2 kg ai/ha and chlorpyrifos at 2.4 kg ai/ha applied at pegging to control the southern corn rootworm. Fungicides were applied to control diseases beginning in late June followed with biweekly applications thereafter in the disease preventive strategy. Chlorothalonil (tetrachloroisophtalonitrile) was applied at 1.1 kg ai/ha in late June through mid-July. From mid-July through late August in 1997, 1.1 kg/ha chlorothalonil + 0.31 kg ai/ha flutolanil {*N*-[3-(1-methylethoxy)-phenyl]-2-(trifluoroethyl)-benzamide} was applied. In 1998, 0.23 kg ai/ha tebuconazole {α-[2-(4-chlorophenyl)-ethyl]-α-(1,1-dimethylethyl) was used for these sprays. A final spray of chlorothalonil at 1.1 kg/ha was applied in September. When field histories suggested that Sclerotinia blight was present, iprodione [3-(3,5-dichlorophenyl)-*N*-(1-methylethyl)-2,4-dioxo-1-imidazolidinecarboxamide] at 1.1 kg ai/ha was applied in late July. Metam sodium at 38 L/ha was applied 2 wk before planting in the disease preventive strategy at Bladenboro, Lewiston, and Windsor. The weed preventive strategy included greater emphasis on prophylactic preemergence and ground-cracking herbicide applications. Additional postemergence herbicides were applied when target species were observed, but not based on economic thresholds. All plots in the weed preventive strategy received the same herbicide treatment regardless of weed population. Cost of pest management strategies and specific inputs are provided in Table 1.

IPM Strategy. The IPM approach involved scouting for insects, weeds, and diseases or the damage caused by these pests using currently available information on economic thresholds, field histories, or available weather-based advisories (Johnson *et al*., 1985; Linker *et al*., 1991; Bailey and Shew, 1998; Herbert, 1999). The PEANUT HERB model was used to target postemergence herbicide applications for individual plots in the weed IPM strategy (White and Coble, 1997; MacDonald *et al*., 1998). Weed densities were determined in early June and mid-July during both years, and in early August during 1997. Economic thresholds were used to target application of acephate (1.1 kg ai/ha) to control tobacco thrips based on a threshold of 25% leaflet damage during the first month after planting in the insect IPM strategy (Herbert, 1999). Fall armyworm, *Spodoptera frugipera* (J. E. Smith), and corn earworm populations did not reach thresholds of 13 larvae/m row (Herbert, 1999). The decision to apply chlorpyrifos (2.5 kg/ha) at pegging to control southern corn rootworm in the insect IPM strategy was based on the Southern Corn Rootworm Index (SCRW Index) being developed by Herbert *et al.* (1997). The SCRW Index ranks fields into categories of low, moderate, and high risk of damage from southern corn rootworm based on planting date, cultivar selection, soil drainage characteristics, soil texture, field history relative to presence of southern corn rootworm, and irrigation. Host-plant resistance (NC 12C) was used at Lewiston and Windsor to manage CBR. Field histories at these locations indicated low levels of this disease. At Bladenboro, a higher level of CBR was anticipated because it was estimated that at least 10% of plants were diseased by CBR the last time peanut was grown in this field. Therefore, the cultivar NC 12C and fumigation with metam sodium (38 L/ha) were used in the disease IPM strategy. Weather-based advisories were used to schedule fungicide sprays to control foliar diseases, southern stem rot, rhizoctonia limb and pod rot, and Sclerotinia blight in the disease IPM strategy (Bailey and Shew, 1998).

Data Collected. The percentage of leaflets damaged by tobacco thrips was recorded 1 and 3 wk after peanut emergence in the center two rows of each plot. Potato leafhopper damage (often referred to as potato leafhopper burn) on individual leaflets was recorded in late July using a scale of 0 to 100% where 0 = no leaflet burn and 100% = all leaflets expressing burn. With respect to early and late (*Cercosporidium personatum* Berk. et Curt.) leaf spot, the percentage of leaflets with one or more lesions was recorded in early September. Infection and damage by southern stem rot or rhizoctonia was not documented in these experiments. Damage caused by Sclerotinia blight was determined in mid-July and at harvest by counting the number of 0.3-m spaces with disease present in the center two rows of each plot. Damage caused by CBR was determined in mid-September based on the same procedure used for Sclerotinia blight. In both instances the percentage of diseased plants was calculated based on actual counts. Twenty-five pods per plot (1997) or 100 pods per plot (1998) were randomly removed from plants in early September to determine the percentage of pods damaged by southern corn rootworm. The percentage of plants showing damage from the twospotted spider mite was recorded in late August on a scale of 0 to 100% where 0 = no foliar damage to 100 = all foliage expressing damage.

Peanut was harvested using conventional harvesting equipment. One kilogram of pods was collected at harvest from each plot to determine percentage fancy pods, extra large kernels, total sound mature kernels, and other kernels using North Carolina Dept. of Agric. Grading Service guidelines. Economic value per kilogram farmer stock peanut was determined based on the grade characteristics. Gross value ($/ha) was determined based on the combination of grade factors and pod yield. Gross returns reflect the current quota price of $0.75/kg (Brown, 1998). Economic return was estimated as the difference between gross economic

Table 1. Pest management inputs for eight experiments conducted in North Carolina peanut fields in 1997 and 1998.[a]

Pest management strategy			Location and year							
			Lewiston		Rocky Mount		Tyner			
Disease	Insect	Weed	1997	1998	1997	1998	1997	1998	Windsor	Bladenboro
Preventive	Preventive	Preventive	MET	MET	ALD	ALD	RVAR	RVAR	MET	MET
			RVAR	RVAR	CHLR	CHLR	ALD	ALD	RVAR	RVAR
			ALD	ALD	CAL	CAL	CHLR	CHLR	ALD	ALD
			CHLR	CHLR	IPR	PROP	CAL	CAL	CHLR	CHLR
			CAL	CAL	PROP		IPR	PROP	CAL	CAL
			IPR	IPR		PROP		IPR	PROP	
			PROP	PROP				PROP		
Preventive	Preventive	IPM	MET	MET	ALD	ALD	RVAR	RVAR	MET	MET
			RVAR	RVAR	CHLR	CHLR	ALD	ALD	RVAR	RVAR
			ALD	ALD	CAL	CAL	CHLR	CHLR	ALD	ALD
			CHLR	CHLR	IPR	HERB	CAL	CAL	CHLR	CHLR
			CAL	CAL	HERB	IPR	HERB	CAL	CAL	
			IPR	IPR		HERB		IPR	HERB	
			HERB	HERB					HERB	
Preventive	IPM	Preventive	MET	MET	ACE	ACE	RVAR	RVAR	MET	MET
			RVAR	RVAR	CAL	CAL	ACE	ACE	RVAR	RVAR
			ACE	ACE	IPR	PROP	CAL	CAL	ACE	ACE
			CAL	CAL	PROP		IPR	HERB	CAL	CAL
			IPR	IPR			PROP	CHLR	IPR	PROP
			PROP	PROP					PROP	
Preventive	IPM	IPM	MET	MET	ACE	ACE	RVAR	RVAR	MET	MET
			RVAR	RVAR	CAL	CAL	ACE	ACE	RVAR	RVAR
			ACE	ACE	IPR	HERB	CAL	CAL	ACE	ACE
			CAL	CAL	HERB		IPR	PROP	CAL	CAL
			IPR	IPR			HERB	CHLR	IPR	HERB
			HERB	HERB					HERB	
IPM	Preventive	Preventive	RVAR	RVAR	ALD	ALD	RVAR	RVAR	RVAR	MET
			ALD	ALD	CHLR	CHLR	ALD	ALD	ALD	RVAR
			CHLR	CHLR	WBA	WBA	CHLR	CHLR	CHLR	ALD
			WBA	WBA	PROP	PROP	WBA	WBA	CAL	CHLR
			PROP	PROP			IPR	PROP	PROP	WBA
							PROP			PROP
IPM	Preventive	IPM	RVAR	RVAR	ALD	ALD	RVAR	RVAR	RVAR	MET
			ALD	ALD	CHLR	CHLR	ALD	ALD	ALD	RVAR
			CHLR	CHLR	WBA	WBA	CHLR	CHLR	CHLR	ALD
			WBA	WBA	HERB	HERB	WBA	WBA	CAL	CHLR
			HERB	HERB			IPR	HERB	HERB	WBA
							HERB			HERB
IPM	IPM	Preventive	RVAR	RVAR	ACE	ACE	RVAR	RVAR	RVAR	MET
			ACE	ACE	WBA	WBA	ACE	ACE	ACE	RVAR
			WBA	WBA	PROP	PROP	WBA	CHLR	CAL	ACE
			PROP	PROP			IPR	PROP	PROP	WBA
							PROP			HERB
IPM	IPM	IPM	RVAR	RVAR	ACE	ACE	RVAR	RVAR	RVAR	MET
			ACE	ACE	WBA	WBA	ACE	ACE	ACE	RVAR
			WBA	WBA	HERB	HERB	WBA	WBA	CAL	ACE
			HERB	HERB			IPR	HERB	HERB	WBA
							HERB	CHLR		HERB

[a]Abbreviations: ALD, aldicarb applied in-furrow; ACE, acephate applied postemergence; CAL, calender fungicide applications biweekly; CHLR, chlorpyrifos applied for southern corn rootworm. HERB, PEANUT HERB for weed management based on economic thresholds; IPR, iprodione applied for Sclerotinia blight suppression; MET, fumigated with metam sodium; PROP, prophylactic herbicide applications; RVAR, resistant variety; WBA, weather-based advisories to schedule fungicide sprays.

value and total operating, interest, ownership, and labor costs using a budget developed by Brown (1998). Costs of all production practices other than those used for disease, insect, and weed management were held constant at $1,235/ha. Pest management costs are provided in Table 2. Average costs of fungicides, fumigant, insecticides, and herbicides were based on prices quoted by two major agrichemical suppliers in northeastern North Carolina.

Experimental Design and Analyses. The experimental design was a split plot with four replications. Disease management strategies (preventive and IPM) were main plots and insect/weed management strategies were subplots. Data for peanut foliage and pod damage, pod yield, gross value, and economic returns were subjected to analyses of variance appropriate for the factorial treatment arrangement. Means for appropriate main effects and interactions were separated using Fisher's Protected LSD Test at P = 0.05.

Results

Significant interactions of experiment by treatment factors prevented pooling of data over experiments. Although significant main effects and two-way interactions among pest management strategies were noted, interactions of disease management by insect management by weed management were not significant for pod yield, gross value, and economic return. Data are presented for significant main effects and interactions for each location and year combination.

Lewiston, 1997. The main effect of disease management and the interaction of disease management by weed management were significant for economic return. The main effect of insect management and the interaction of insect management by disease management or weed management were not significant for this variable. Economic return was greater when disease management was IPM-based rather than preventive regardless of the weed management strategy (Table 3). Higher economic return with the IPM disease strategy most likely resulted from greater costs incurred in the preventive disease management strategy compared with the IPM disease management strategy (Tables 1 and 2). The preventive strategy included fumigation with metam sodium to control CBR, two additional fungicide sprays for early and late leaf spot control, and one application of iprodione for Sclerotinia blight suppression. These control practices were not included in the IPM strategy. Less than 5% of plants were affected by CBR regardless of weed or insect management strategies or whether metam sodium was applied (data not presented). Additionally, Sclerotinia blight incidence was low; therefore, application of iprodione was not economically beneficial in the preventive disease strategy. Applying fungicides biweekly or using the weather-based advisory were equally effective in controlling early and late leaf spot (data not presented). These factors contributed to the greater economic return with the IPM-based disease management strategy.

When coupled with preventive disease management, weed management strategy did not affect economic return (Table 3). In contrast, economic return was greater when weed management was IPM-based rather than preventive in concert with IPM-based disease management. Because pod yield and gross value were not affected by weed management strategies, greater economic return most likely was associated with less expense in the IPM weed management strategy. The preventive weed management strategy received a ground-cracking application of dimethenamid {2-chloro-*N*-[(1-methyl-2-methoxy)ethyl]-*N*-(2,4-dimethyl-thien-3-yl)-acetamide} that was not applied in the weed management IPM

Table 3. Influence of disease and weed management systems on gross value and economic returns of peanut grown at Lewsiton, NC in 1997.[a]

Disease management	Weed management: Economic return, Preventive	Weed management: Economic return, IPM
	$/ha	
Preventive	459	437
IPM	661	1094
LSD (0.05)		
Within disease management	259	
Across disease management	555	

[a]Data are pooled over levels of insect management.

Table 2. Variable cost associated with pest management strategies in peanut.

Pest management strategy: Disease	Insect	Weed	Lewiston 1997	Lewiston 1998	Rocky Mount 1997	Rocky Mount 1998	Tyner 1997	Tyner 1998	Windsor	Bladenboro
			$/ha							
Preventive	Preventive	Preventive	689	439	613	427	618	417	559	524
Preventive	Preventive	IPM	626	432	548	427	585	435	548	522
Preventive	IPM	Preventive	579	366	492	329	508	364	449	435
Preventive	IPM	IPM	500	343	417	329	506	374	423	421
IPM	Preventive	Preventive	398	343	347	380	519	383	389	492
IPM	Preventive	IPM	295	334	303	372	514	373	343	501
IPM	IPM	Preventive	287	254	272	282	409	331	316	403
IPM	IPM	IPM	202	234	192	279	365	343	225	377

strategy. Imazapic {(±)-2-[4,5-dihydro-4-methyl-4-(1-methylethyl)-5-oxo-1*H*-imidazol-2-yl]-5-methyl-3-pyridinecarboxylic acid} and bentazon [3-(1-methylethyl)-(1*H*)-2,1,3-benzothiadiazin-4(3*H*)-one 2,2-dioxide] also were applied to all plots in the preventive weed management strategy. In the IPM weed management strategy, paraquat (1,1'-dimethyl-4,4'-bipyridinium ion), acifluorfen {5-[2-chloro-4-(trifluoromethyl)phenoxy]-2-nitrobenzoic acid}, and bentazon were applied to some but not all plots depending upon the PEANUT HERB recommendation. Additionally, imazapic, the most expensive postemergence herbicide option available in peanut, was not applied in the IPM strategy.

Windsor, 1997. Disease and insect management strategy main effects were significant for pod yield and gross value (Table 4). The main effect of weed management and two-way interactions involving disease, insect, or weed management were not significant for pod yield, gross value, and economic return. Disease management also affected economic return. Pod yield, gross value, and economic return were lower in the IPM-based strategy compared with the preventive strategy (Table 4). Lower yield, and loss of gross value and economic return in the IPM strategy, most likely resulted from greater yield loss due to presence of CBR. The percentage of plants lost to CBR was 4% when plots were fumigated with metam sodium compared with 16% in the IPM disease management strategy where metam sodium was not applied (Table 5). Greater economic return was noted in the preventive disease management strategy even though iprodione was applied for Sclerotinia blight and no Sclerotinia blight developed (data not presented).

Table 4. Influence of disease and insect management strategies on pod yield, gross value, and economic returns of peanut grown in Windsor, NC in 1997.[a]

Pest management	Pod yield	Gross value	Economic return
	kg/ha	$/ha	$/ha
Disease			
Preventive	4219	3078	1343
IPM	3644	2664	1103
Insect			
Preventive	4061	2964	NS
IPM	3794	2773	NS

[a]Data for both the main effect of disease and insect management are pooled over levels of weed management. Data for insect management are pooled over levels of disease management while data for disease management are pooled over levels of insect management. Means for each parameter within a main affect are significantly different at P = 0.05.

Pod yield and gross value were lower in the IPM insect management strategy compared with the preventive strategy (Table 4). No difference in pod damage caused by the southern corn rootworm was noted between the two insect management strategies (data not presented). Also, differences in control of tobacco thrips between aldicarb and acephate could not explain differences noted between the IPM and preventive strategies for pod yield and gross value (data not presented). However, foliar damage caused by potato leafhopper was 40% in the IPM strategy compared with 3% in the preventive strategy (Table 5). Chlorpyrifos, which was applied at pegging in the preventive strategy for southern corn rootworm management, also controls potato leafhopper (Brandenburg, 1998). Greater injury from this insect in the IPM strategy most likely resulted because chlorpyrifos was not applied. However, economic return between the two insect management strategies did not differ, which suggests that the added control gained by chlorpyrifos did not exceed the amount of economic loss due to potato leafhopper when chlorpyrifos was not applied. The impact of potato leafhopper damage on peanut yield is poorly understood (Brandenburg, 1998).

Tyner, 1997. At this location the main effect of insect management was significant for pod yield and gross value (Table 6). Additionally, the interaction of insect and disease management was significant for economic return. Weed management main effects and interactions of weed management with insect or disease management strategies were not significant for these parameters. Pod yield and gross value were lower in the IPM insect management strategy compared with the preventive insect management strategy (Table 6). Tobacco thrips damage was 35% in the preventive strategy (aldicarb applied in-furrow) compared with 66% damage in the IPM strategy (acephate applied postemergence) (Table 5). Additionally, approximately 8% of pods were damaged by southern corn rootworm when chlorpyrifos was applied at pegging compared with 28% without chlorpyrifos (Table 5).

Economic returns were lower when IPM strategies were used for insect management (Table 6). Lower economic return most likely resulted from lower yield

Table 5. Main effect of disease management on control of CBR and twospotted spider mite and main effect of insect management on control of potato leafhopper, tobacco thrips, and southern corn rootworm on peanut grown in North Carolina.[a]

Pest management	Windsor, 1997		Tyner, 1997	Rocky Mount, 1997	Southern corn rootworm		
strategy	CBR	Potato leafhopper	Tobacco thrips	Twospotted spider mite	Lewiston, 1998	Tyner, 1997	Bladenboro
	% Dead plants	% Leaflets damaged	% Leaflets damaged	% Leaflets damaged	% Pods damaged		
Preventive	4	3	35	39	3	8	2
IPM	16	40	66	13	30	28	26

[a]Means within a location for each pest are significantly different at P = 0.05. Data for disease control are pooled over insect and weed management. Data for insect control are pooled over levels of disease and weed management.

Table 6. Influence of insect and disease management strategy on pod yield, gross value, and economic returns of peanut grown in Tyner, NC in 1997.[a]

			Economic return	
			Disease mgmt.	
Insect management	Pod yield	Gross value	Preventive	IPM
	kg/ha	$/ha	--------- $/ha --------	
Preventive	4589	3248	1409	1494
IPM	3933	2699	1124	910
LSD (0.05)				
Within disease management			276	
Across disease management			423	

[a]Data for pod yield and gross value are pooled over levels of weed and disease management. Data for economic return are pooled over levels of weed management. Means for pod yield and gross value for the main effect of insect management are significantly different at P = 0.05.

and gross value as a result of damage from tobacco thrips and southern corn rootworm. Economic savings in the IPM insect strategy offered by use of acephate, as compared with aldicarb and not applying chlorpyrifos, did not offset revenue loss from lower yield. When insect management was preventive, no difference in economic return was noted between the preventive and IPM disease management strategies. In contrast, lower economic return was noted in the IPM disease strategy when insect management was IPM-based rather than preventive. Chlorpyrifos may have contributed to southern stem rot or rhizoctonia limb and pod rot control when disease management was preventive (Melouk and Backman, 1995). Incidence and damage from these pests were not recorded.

Rocky Mount, 1997 and 1998. Disease management strategy significantly affected pod yield, gross value, and economic return. All other main effects and interactions were not significant. Pod yield, gross value, and economic return were higher in the IPM strategy compared with the preventive disease management strategy (Table 7). Higher pod yield, gross value, and economic return most likely were associated with twospotted spider mite infestation and damage to peanut. In 1997, foliar damage caused by the twospotted spider mite was 39% in the disease preventive strategy compared with

Table 7. Influence of disease management strategies on pod yield, gross value, and estimated economic returns of peanut grown at Rocky Mount, NC in 1997 and 1998.[a]

	Pod yield		Gross value		Econ. return	
Disease mgmt	1997	1998	1997	1998	1997	1998
	--- kg/ha ---		--- $/ha ---		----- $/ha ----	
Preventive	3544	5134	2458	3658	699	2044
IPM	4569	5603	3087	3985	1571	2422

[a]Data are pooled over levels of insect and weed management. Means for each parameter within a year are significantly different at P = 0.05.

13% damage in the IPM disease management strategy (Table 5). Damage from twospotted spider mite infestation was not recorded in 1998, although some damage was present (data not presented).

Lewiston, 1998. Weed and disease management strategies did not affect pod yield, gross value, or economic return. In the IPM-based insect management strategy, pod yield, gross value, and economic return were higher in the preventive strategy compared with the IPM strategy (Table 8). Lower gross value and less economic return most likely resulted from lower pod yields associated with pod damage from southern corn rootworm. Thirty percent of pods were damaged by southern corn rootworm in the IPM insect strategy when chlorpyrifos was not applied compared with only 3% damage when chlorpyrifos was applied at pegging (Table 5).

Table 8. Influence of insect management strategies on pod yield, gross value, and estimated economic returns of peanut grown at Lewiston, NC in 1998.[a]

Insect mgmt.	Pod yield	Gross value	Econ. return
	kg/ha	$/ha	$/ha
Preventive	4990	4137	2513
IPM	3771	3001	1466

[a]Data are pooled over levels of disease and weed management. Means for pod yield and gross value for the main affect of insect management are significantly different at P = 0.05.

Bladenboro, 1998. The interaction of disease and insect management strategy was significant for pod yield, gross value, and economic return; and they were higher when insect management was preventive rather than IPM-based (Table 9). This difference most likely resulted from greater pod damage caused by the southern corn rootworm in the IPM insect management strategy (26%) compared with the preventive strategy (2%) which received chlorpyrifos at pegging (Table 5). Control of

Table 9. Influence of insect and disease management strategies on pod yield, gross value, and economic return of peanut grown at Bladenboro, NC in 1998.

Disease	Insect management strategy					
mgmt.	Pod yield		Gross value		Economic return	
strategy	Preventive	IPM	Preventive	IPM	Preventive	IPM
	-----kg/ha-----		-----$/ha-----		-----$/ha-----	
Preventive	5271	4821	4234	3906	2476	2242
IPM	5656	4292	4529	3343	2797	1717
LSD (0.05)						
Within disease mgmt.	228		223		233	
Across disease mgmt.	345		349		353	

[a]Data are pooled over levels of weed management.

tobacco thrips was similar with aldicarb and acephate (data not presented). Pod yield, gross value, and economic return also were lower with the IPM-based disease management strategy compared with the preventive strategy when insect management was IPM-based. Pod yield, gross value, and economic return were higher when insect management was preventive rather than IPM-based. Although southern stem rot damage and rhizoctonia limb and pod rot damage were not quantified, it is possible that chlorpyrifos applied in the preventive strategy reduced incidence of these diseases (Melouk and Backman, 1995)

Pod yield, gross value, and economic return were greater with the IPM disease management strategy compared with the preventive disease management strategy when insect management was preventive (Table 9). The only difference between the preventive and IPM disease management strategies was an early application of chlorothalonil to control early leaf spot in the preventive strategy. This application was made under conditions not favorable for leaf spot development based on weather-based advisories, but at a time when many growers begin biweekly spray schedules for early leaf spot control. Preventing epidemics from developing when managing early leaf spot is important. However, there were no differences in early or late leaf spot control in this experiment (data not presented). Although southern stem rot was present in the study, there appeared to be no difference in control among the disease management strategies. Higher pod yield, gross value, and economic return in the IPM disease management strategy compared with the preventive strategy could not be explained.

Discussion

Collectively, these data demonstrate the complexity of pest management in peanut as well as weaknesses and strengths of current pest control and IPM practices. The importance of accurate identification of pests and gathering detailed field histories also was demonstrated. Likewise, a thorough understanding of production practices and timely implementation of pest control tactics is critical for plant protection.

The importance of managing CBR was demonstrated at Windsor in 1997. Damage exceeded economic threshold levels in nontreated plots at this location, and fumigation was critical in maintaining pod yield and economic return. The cultivar NC 12C exhibits the highest level of CBR resistance among commercially acceptable virginia market types (Linker *et al.*, 1991; Bailey and Shew, 1998), but the level of CBR resistance was not sufficient to prevent yield loss. The level of damage observed in this experiment, while only 16% plant loss, justified fumigation. In contrast, although CBR was anticipated at Lewiston in 1997 and 1998, there was no economic advantage to fumigation in either year at this location, and even a disadvantage in terms of economic return in 1997. Previous field histories suggested that CBR was present, although the degree of damage expected from this disease was not known. It is possible that threshold levels were not present in these fields and more quantitative records would have allowed better decisions on fumigation. However, economic thresholds for CBR damage, especially when predicting yield loss in subsequent growing seasons, are not well established (Pataky *et al.*, 1983; Bailey and Shew, 1998; Linker *et al.*, 1991). Also, tomato spotted wilt virus often is present at this location, and the decision to fumigate in the preventive strategy may have been associated with attributing prior plant loss to CBR when, in fact, damage was the result of tomato spotted wilt. Fumigation does not affect tomato spotted wilt (Bailey and Shew, 1998). Tomato spotted wilt virus was present, but incidence did not differ among pest management strategies (data not presented). Selection of the cultivar NC-V11 may have been a better choice for tomato spotted wilt virus management because it offers some field resistance to the virus compared with NC 12C (Bailey and Shew, 1998).

Implementation of the SCRW Index was a weakness in these studies. Although plots were irrigated at Tyner in 1997 and Lewiston in 1998, the original decision of whether to apply chlorpyrifos was based on the assumption that peanut was not irrigated. At Tyner in 1997 this was a management mistake. At Lewiston, peanut was irrigated late in the season after the decision to apply chlorpyrifos had been made. The SCRW Index suggested that these were low risk fields and chlorpyrifos was not applied in the IPM insect management strategy. At both locations, significant pod damage from southern corn rootworm was noted, and pod yield and economic return were improved in the preventive strategy when chlorpyrifos was applied. At Bladenboro, the SCRW Index suggested peanut was in a low risk field. Although peanut was not irrigated at this location, rainfall was abundant throughout the time plants were pegging. Abundant rainfall combined with excessive vine growth from NC 12C may have created an environment conducive to southern corn rootworm survival and development. Less pod damage was noted at this location when chlorpyrifos was applied, which most likely affected yield and subsequently economic value. Additionally, a more complete field history may have suggested that southern corn rootworm populations are traditionally high, and this may have resulted in treatment with chlorpyrifos. Chlorpyrifos was applied the last few times peanut was grown in this field and may have masked potential of damage from this insect. The need for accurate population assays or field histories is a weakness in the current index (Herbert *et al.*, 1997), primarily because insecticides have been used extensively to control southern corn rootworm. Further refinement of the SCRW Index is needed to avoid outcomes similar to that noted in Bladenboro. These data suggest that pod damage from southern corn rootworm in the range of 26 to 30% can cause yield and economic loss.

At Bladenboro in 1998, higher yield and economic return was noted when the insect management strategy was preventive regardless of the disease management strategy. Although not documented, suppression of these soilborne pathogens by chlorpyrifos may have contributed to higher yields and returns (Melouk and Backman, 1995).

Control of tobacco thrips by aldicarb or acephate was similar in seven of eight experiments. These data suggest that timely postemergence applications of acephate, based on economic thresholds, can control tobacco thrips as well as prophylactic applications of aldicarb. Tobacco thrips levels exceeded threshold levels in all fields, and timely applications of acephate controlled this pest as well as aldicarb except in one experiment. Timely applications are critical in this approach to management of tobacco thrips. Potential benefits of nematode control by aldicarb were not addressed in these studies.

Controlling early and late leaf spot using the weather-based advisory was as effective as applying fungicides biweekly. However, at Bladenboro the early application of chlorothalonil may have been beneficial in increasing yield and economic value in the preventive strategy even though differences in early leaf spot control were not observed by the end of the season. With the exception of Windsor in 1997, where leaf spot control programs were the same for both preventive and IPM disease management strategies, targeting fungicide sprays based on the weather-based advisory saved costs associated with one to three additional sprays used in the preventive strategy. Also, data at Rocky Mount suggested that fewer fungicide sprays reduce the likelihood of enhancing spider mite damage. Greater damage from twospotted spider mites in the preventive program most likely resulted from suppression of fungal pathogens of mites [(*Neozygites floridana* (Weiser and Muma)] (Brandenburg, 1998).

The decision to apply iprodione for Sclerotinia blight suppression also was a weakness in this study. Applications of iprodione at Lewiston, Windsor, and Rocky Mount in 1997 were not justified because little disease developed. To be effective, iprodione needs to be applied prior to development of disease symptoms. Knowing the level of infestation of *Sclerotinia minor* is critical in determining if fungicide sprays are economically justified. At Tyner in 1997, weather conditions favored development of Sclerotinia blight, and two applications each in the IPM and preventive disease management strategies most likely were justified. However, iprodione was applied after disease symptoms had developed because field histories suggested that *Sclerotinia minor* was not present. More accurate field histories would prevent unnecessary fungicide applications and would increase precision of necessary applications.

Applying herbicides prophylactically compared with applications based on weed thresholds had only minor effects on pod yield, gross value, and economic return. The exception was Lewiston in 1997 where applying herbicides based on weed thresholds resulted in increased economic return. At this location, dimethenamid, imazapic, and bentazon were applied in the preventive strategy. Although imazapic was effective on the weeds present at this location, it is the most expensive herbicide registered for use in peanut. In the IPM weed management strategy, less expensive herbicides were applied based on the PEANUT HERB recommendation. Also, in several plots the weed populations and potential yield loss did not justify herbicide use which contributed to the lower cost of weed management in the IPM strategy. Lack of differences in pod yield and gross value between the two management strategies suggests that highest economic return was associated with more judicious use of herbicides. At the other seven locations the decision to apply herbicides prophylactically or based on the PEANUT HERB did not affect pod yield, gross value, or economic return. However, applying herbicides in this manner reduced variable costs associated with weed management and also reduced the amount of herbicide applied.

These studies clearly demonstrate the need for accurate pest identification and field histories, a thorough understanding of all production and pest management strategies and their interactions, and the importance of timely implementation of control practices for success of IPM strategies. These studies also document ramifications of overuse of pesticides and how this can affect secondary pest outbreaks. Scouting costs were not included when calculating economic return. The complexity of implementing a completely IPM-based approach for disease, insect, and weed management most likely would require hiring a consultant.

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