Weather-Based Crop and Disease Advisories for Peanuts in Virginia

World peanut production averages 23 million metric tons from harvest of approximately 20 million hectares on six continents (2). India, China, and the United States produced 70% of the world's peanuts in 1990 and 1991. Production in the United States is concentrated in the southeast (Georgia, Florida, and Alabama), southwest (Texas and Oklahoma), and the mid-Atlantic region (Virginia, North Carolina, and South Carolina). Peanuts are grown in sandy-textured soils in warm, moist climates having a growing season of 140 or more days. Southeastern Virginia provides an excellent environment for commercial production, as evidenced by high yield and quality dating back to the Civil War (8). Today, the industries of producing, shelling, and processing peanuts are major pillars of the economy in southeastern Virginia. These industries are concentrated in an eight-county area, where the value of the crop to growers often ranges from \$80 to \$102 million, as in 1994 and 1990, respectively.

Unfortunately, the warm and moist climate necessary for peanut production makes fungal diseases a chronic threat to profits. The rapid spread and the unforgiving nature of early leaf spot, caused by *Cercospora arachidicola* S. Hori, have earned the respect of growers in Virginia and around the world. Peanut growers are also keenly aware of soilborne diseases caused by fungi such as *Sclerotinia minor* Jagger (*Sclerotinia* blight), *Sclerotium rolfsii* Sacc. (southern stem rot), and

Cylindrocladium parasiticum Crous, Wingfield & Alfenas (*Cylindrocladium* black rot). In 1990 and 1991, a systematic survey of peanut growers in southeastern Virginia was conducted to evaluate their perception of losses of yield to specific diseases and the use of pesticides (11; P. M. Phipps, *unpublished*). *Sclerotinia* blight and southern stem rot were named most frequently as responsible for yield losses exceeding 10% (Table 1). *Sclerotinia* blight was considered by the highest percentage of growers to be the most damaging disease. Clinical records, on-farm tests, and reports by extension agents and specialists supported these estimates, except for the claims of yield losses to southern stem rot. In this case, it was thought that the growers' estimate of losses may have been excessive and possibly reflected some confusion with *Sclerotinia* blight.

Peanuts require intensive management because of the crop's vulnerability to yield losses caused by diseases, insects, and

weeds. Chemicals play a major role in pest management strategies for peanut production due to the limited availability of acceptable alternatives. Based on the 1990 survey of peanut growers in Virginia, the input of pesticide active ingredients (a.i.) totaled 747 t and averaged 19 kg/ha (Table 2). The cost of these materials averaged \$293 per ha. With the dramatic increase in the use of metam sodium for control of *Cylindrocladium* black rot (CBR) in 1991, the estimated input of pesticide a.i. totaled 970 t and averaged 25 kg/ha at a cost of \$322 per ha. Metam sodium accounted for 36% of the total a.i. and 9% of cost. Chemicals for disease management alone accounted for 37 and 42% of the total cost of pesticides for production in 1990 and 1991, respectively.

Recent changes in government programs (1) that control production quotas and prices growers receive for U.S. peanuts were expected to cause up to a 10% reduction in acreage and a 10% reduction in

Table 1. Estimated losses of yield to peanut diseases based on a systematic survey of growers in Virginia^y

Disease	1990			1991		
	None	<10%	≥10%	None	<10%	≥10%
Nematode damage	50	38	12	14	83	3
Seedling disease	90	7	3	83	17	0
<i>Cylindrocladium</i> black rot	16	72	12	17	69	14
<i>Sclerotinia</i> blight	15	49	36	13	47	40
Early leaf spot	65	21	14	36	58	6
Southern stem rot	30	49	21	27	57	16
Rhizoctonia limb rot	84	13	3	71	29	0
Pod rot	75	16	9	45	55	0
Tomato spotted wilt virus ^z	...	...	...	78	22	0

^y Data are the percent of 35 growers in 1990 and of 32 growers in 1991 who reported a given level of yield loss to each disease.

^z Tomato spotted wilt virus in peanuts was first recognized in Virginia in 1989. This disease was not included in the 1990 survey since growers were just beginning to recognize the problem.

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market price in 1996. While these changes are designed to reduce government costs, they will also reduce cash receipts from peanut production. In order to sustain a profitable peanut industry, growers must find ways to reduce the cost of production and yet maintain high yield and quality. These needs are expected to increase the demand for technology that can minimize input costs while effectively managing risk for losses of yield and quality.

This article summarizes ongoing programs that utilize weather data, medium-range forecasts, and crop advisory models to improve the efficiency of peanut production in Virginia. Grower acceptance, program delivery, impact, and future opportunities are discussed. Through this publication, it is hoped that readers in the private and public sectors will be encour-

aged to contribute ideas and support for similar programs that improve the efficiency of crop production and reduce the overall dependency on pesticides.

Weather-Related Constraints to Peanut Production

Growers and buyers of peanuts believe that weather is often the single most important factor in determining the success or failure of crops. Weather affects, not only yield and quality, but also the incidence and severity of pests and the efficacy of pesticides. Therefore, up-to-date sources of accurate weather data can be important decision-making aids for all segments of the peanut industry.

Planting and crop growth. Before planting crops in the spring, growers routinely check soil temperatures and weather

forecasts to determine when conditions are favorable for seed germination and emergence of the crop. Peanut seed should be planted in soils that reach 18°C (65°F) or warmer at the 5- to 10-cm depth each day and when forecasts indicate these conditions are likely to continue over the next 3 to 5 days. Cooler temperatures will slow seedling emergence and predispose germ-lings to damping-off caused by seedborne and soilborne microorganisms. Growers are also keenly interested in reports of accumulated heat units and rainfall. These data are widely used to gauge the progress of crop development and to forecast the maturity date and yield potential of peanut.

Early leaf spot. Early leaf spot is the predominant foliar disease of peanut in Virginia. The causal fungus, *C. arachidicola*, requires warm, humid weather for sporulation and infection in peanuts. The disease appears as brown to dark brown spots that are often surrounded by yellow haloes (Fig. 1). Without foliar applications of fungicides, the disease may cause up to 100% defoliation prior to harvest and losses in excess of 50% of potential yield (20). Agronomic practices, such as crop rotation and moldboard plowing to bury crop residues, may reduce levels of initial inoculum in soil, but these approaches have limited value with a polycyclic disease on a long-season crop such as peanut.

Foliar sprays of fungicides are the single most effective method for leaf spot control in Virginia because of inadequate disease resistance in commercial cultivars of the large-seeded, Virginia-type peanut. The extensive use of fungicides, however, has not been without problems. Both *C. arachidicola* and *Cercosporidium personatum* (Berk. & M.A. Curtis) Deighton, the cause of late leaf spot, quickly developed resistance to benomyl and now threaten to develop resistance to ergosterol biosynthesis-inhibiting fungicides such as propiconazole

Table 2. Summary of pesticide use on peanuts in Virginia^y

Item	Units	1990	1991
Herbicide	Metric tons (a.i.)	234	188
	\$(millions)	3.5	3.6
Insecticide	Metric tons (a.i.)	134	119
	\$(millions)	3.6	3.5
Acaricide	Metric tons (a.i.)	3.4	2.7
	\$(millions)	0.06	0.05
Fungicide	Metric tons (a.i.)	314	274
	\$(millions)	2.9	3.1
Nematicide ^z	Metric tons (a.i.)	47	34
	\$(millions)	1.3	1.1
Metam sodium	Metric tons (a.i.)	15	352
	\$(millions)	0.07	1.1
Total harvested	Hectares	39,255	38,850
Total pesticide	Metric tons (a.i.)	747	970
	kg/ha	19.1	24.9
Total cost	\$(millions)	11.5	12.5
	\$/ha	293	322

^y Data are estimates based on results of a systematic survey of growers each year.

^z Nematicide included granular and fumigant materials for control of nematodes, but not *Cylindrocladium* black rot. Metam sodium was used for control of *Cylindrocladium* black rot and nematodes.

and tebuconazole. Furthermore, the repeated use of chlorothalonil at spray intervals of 14 days for control of leaf spot diseases can increase the severity of Sclerotinia blight (16).

Sclerotinia blight. Sclerotinia blight of peanut, caused by *S. minor*, is currently the most destructive disease of peanut in Virginia. Lateral limbs, leaflets, and pegs (botanically a carpophore or gynophore) either in contact or in close proximity with soil are initial sites of disease symptoms (Fig. 2). Disease onset usually occurs after plants develop a dense canopy of foliage that restricts air movement and shades the soil surface from direct sunlight (13). Once these conditions exist, temperature and the availability of moisture are the primary determinants of fungal growth and disease development. Rainfall summaries over a 13-year period (1981 to 1993) in fields at the Tidewater Center in Suffolk have shown a trend for heaviest accumulations from 3 to 17 days before disease onset. The optimum temperature for sclerotial germination and infection of peanut falls between 20 and 25°C (5). Based on records of air temperatures in the 15 days preceding disease onset, air and soil temperatures

commonly fluctuate between levels extremely favorable (20°C) and unfavorable (30°C) for fungal growth in Virginia (13). In Texas, *S. minor* is reported to be inactive in peanut fields after soil temperatures exceed 28°C at the 5-cm depth (9).

Although both moisture and temperature are commonly mentioned as significant factors affecting development of Sclerotinia blight, evidence in the Virginia peanut production area suggests that plant growth and rainfall are the primary forces at work in triggering disease outbreaks (13). Crop rotation and applications of the fungicide iprodione are only partially effective for disease management. No commercially acceptable cultivars of Virginia-type peanut have a high level of resistance to the disease. According to field trials over a 4-year period, losses to the disease averaged approximately 33% of potential yield or 1,598 kg/ha in naturally infested fields (21). Iprodione was registered for control of Sclerotinia blight of peanut in 1985 and provided an average of approximately 31% suppression of disease incidence in these trials. Fluazinam, a new fungicide being developed by ISK Biosciences Corp., provided an average of

69% suppression of disease incidence. Registration of fluazinam and the development of more effective methods to control the disease are urgently needed in Virginia.

Cylindrocladium black rot. Prior to implementation of disease control strategies with metam sodium in 1985, Cylindrocladium black rot (CBR) posed a serious threat to peanut production on many farms in Virginia. Chlorosis and wilt of leaves are the first visible symptoms of CBR. Small, reddish orange perithecia of the pathogen, *Calonectria ilicicola* (Boedyn & Reitsma) (imperfect stage *Cylindrocladium parasiticum*), develop during moist weather in dense clusters on infected stems and pegs near the soil surface (Fig. 3). Microsclerotia enable long-term survival of the fungus in soil and serve as primary inoculum for initiating root infection.

The incidence and severity of CBR in susceptible and resistant cultivars have been shown to depend on inoculum densities in soil and on soil moisture and temperature. These factors have resulted in the erratic performance of resistant cultivars across locations and years. Consequently,

Fig. 1. Typical foliar symptoms of early leaf spot of peanut, caused by *Cercospora arachidicola*.

Fig. 3. Reddish orange perithecia of *Calonectria ilicicola* (imperfect stage *Cylindrocladium parasiticum*), the cause of Cylindrocladium black rot, on peanut stems at the soil surface.

Fig. 2. Symptoms and signs of Sclerotinia blight of peanut, caused by *Sclerotinia minor*.

Fig. 4. Digging and inverting peanuts into windrows for field drying of vines and pods in preparation for harvest.

metam sodium is used widely at 36 kg/ha under bedded rows at least 2 weeks prior to planting for reducing levels of microsclerotial inoculum in the zone of taproot growth (10). For best results, metam sodium should be applied after daily soil temperatures reach 18°C (65°F) and are not likely to fall below 9°C (48°F) at a depth of 10 cm.

Frost. Weather is also very important during harvest, because plant parts must be sufficiently dry for maximum efficiency during combining. The harvest of peanuts begins with inverting the crop into windrows, where plants must dry before combining to remove whole pods (Fig. 4). Field drying usually requires 5 to 10 days, depending on weather conditions. In the first 24 to 72 h after digging, moisture levels in whole pods can be 40% (wt/wt) or sometimes higher. At these levels, peanut kernels are highly susceptible to freeze damage, which produces undesirable flavors (19) and may reduce crop value by more than 50% (1). The chilling temperature, exposure time, and subsequent warming rate are believed to determine the extent of damage. During the chilling period, respiration is thought to change from aerobic to anaerobic, which leads to the accumulation of metabolites responsible for off-flavors in kernels. Temperatures near 0°C or slightly lower are considered chilling temperatures, whereas temperatures in the range from -2.2°C (28°F) to -4.4°C (24°F) are defined as freezing for freshly dug peanuts. Ice nucleation has been estimated to occur at freezing temperatures in approximately 4 or 5 h.

Avoiding exposure to chilling or freezing temperatures during the first few days of open-field drying of peanuts is critical to obtaining a maximum cash value for the crop. Successful harvesting requires knowledge of weather patterns and the risk of frost for a period of 3 to 5 days immediately after digging. The frequency of the first killing frost in Suffolk, Virginia, over the last 64 years has been greatest in the third week of October, with the average date being 20 October. During this period, the progress of peanut harvest can vary from 30 to 80% complete, depending on the growing season and weather conditions during the harvest period. These variables make the timing of harvest impossible to plan on a calendar schedule.

Advisory Programs

Early leaf spot advisory. The early leaf spot advisory is the longest running and most well documented advisory program in terms of benefits to the peanut industry in Virginia. The advisory algorithm uses records of ambient temperature and relative humidity (RH) to detect the occurrence of environmental conditions conducive to infection by *C. arachidicola* (3). Early in the growing season, the

advisory alerts growers at the first occurrence of favorable conditions for infection and the need to apply fungicide. Subsequent advisories report the "last effective spray date" for a fungicide application to still be active in preventing infection (12). Peanuts sprayed before that date are considered vulnerable to infection, and the application of a fungicide is recommended. If a spray was applied since the last effective spray date, then no fungicide is needed. This determination is made by using temperature and RH data and a crop protection period of 10 days, which corresponds to the foliar half-life of chlorothalonil.

An assessment of program benefits from 1987 to 1990 showed that growers can save an average of 2.25 fungicide sprays per season compared with the old 14-day calendar program (12). According to estimates of cost for applications of chlorothalonil at 1.12 kg/ha during that period, the advisory program reduced input cost an average of 33%, or \$57 per ha. Although incidence of early leaf spot was often higher with the advisory program, yields were frequently above those from plots on a 14-day spray program. In 1989, a new advisory algorithm was released that improved leaf spot control through better timing of fungicide sprays (3). Over the period from 1990 to 1995, the program averaged a savings of three fungicide sprays per season, reduced input cost by 43% or \$66 per ha, and increased net return by 26% or \$225 per ha compared with a 14-day program (Table 3). The savings in input costs alone were \$2,640 per year for the average grower, who manages approximately 40 ha of peanuts in Virginia. Net returns compared with the 14-day

program were increased by \$9,000 per year. Yield advantages of the advisory program have been attributed to reduced vine damage and soil compaction by tractor tires and a reduction in severity of Sclerotinia blight (16,17).

Sclerotinia blight advisory. Based on results of field tests and assessments of disease development over a 16-year period (13), an algorithm was developed to produce daily advisories for warning growers of the risk for disease onset and the need for fungicide application (14). This algorithm uses environmental factors and the condition of the host plant to estimate the risk for disease (Fig. 5). Vine growth and the density of the foliar canopy are used to determine host vulnerability. Plant growth indices of three, two, or one are assigned when vines are overlapping between rows, ≤15 cm from overlapping, or >15 cm from overlapping, respectively. Likewise, numerical indices of three, two, or one are assigned to the foliar canopy when ≥95%, ≥75%, or <75% of the soil surface is shaded by foliage. The effect of environment on disease is determined by indices of moisture and soil temperature. Moisture is assigned an index of one each day if RH is ≥95% for eight or more consecutive hours or if accumulations of rainfall are ≥1.27 cm (0.5 inch) over the previous 5 days or ≥2.54 cm (1 inch) over the previous 10 days. Otherwise, the moisture index is zero. Soil temperature indices are three, two, one, or zero when daily averages at the 10-cm depth are ≤22°C (71.6°F), ≤25°C (77°F), ≤28°C (82.4°F), or >28°C, respectively. A daily risk index (DRI) is computed by multiplying the indices of each parameter for a given day. The 5-day index (FDI) is the sum of DRI values for

Table 3. Performance and economic benefit of the Virginia peanut leaf spot and Sclerotinia blight advisory programs

Spray program ^v	No. of appl.	Cost (\$/ha) ^w	Disease at harvest ^x	Yield (kg/ha) ^y	Gross value (\$/ha)	Net return (\$/ha)
Early leaf spot trials (1991 to 1995)						
Advisory	4	88.98	16.4 b ^z	3,878 a	2,516 a	1,104 a
14-day	7	155.27	5.4 c	3,636 a	2,361 ab	879 ab
Check	0	0	86.0 a	3,273 b	2,125 b	800 b
Sclerotinia blight trials (1994 to 1995)						
Advisory	2.4	257.58	1,105 b	3,105 a	1,974 a	257 a
Demand	2.4	257.58	1,108 b	2,963 a	1,890 a	173 a
Check	0	0	1,775 a	2,185 b	1,384 b	-75 b

^v Leaf spot trials (one per year) used chlorothalonil at 1.26 kg/ha. Sclerotinia blight trials (five in 1994, four in 1995) used iprodione at 1.12 kg/ha.

^w Computations of cost were determined using estimated variable costs provided by the farm management staff, Southeast District, Virginia Cooperative Extension.

^x Early leaf spot based on visual estimates of percentage of leaflets with early leaf spot. Sclerotinia blight based on counts of disease foci per plot during the growing season and expressed as area under the disease progress curve.

^y Yield of peanuts at 7% moisture (wt/wt). Gross value was based on the average seasonal price per unit of production. Net return was determined by subtracting the estimated total production cost from gross value.

^z Means within a group and column followed by the same letter(s) are not significantly different at *P* = 0.05 according to the Waller-Duncan *k*-ratio *t* test.

the previous 5 days and provides a measure of risk for infection. An FDI level of 32 has been designated as the threshold for initiating fungicide treatment in fields with a history of disease. After a treatment is applied, all indices are held at zero for a 3-week period to reflect the protection period of the fungicide treatment. Upon expiration of this period, the model begins computing DRI and FDI values for determining when to make the next fungicide application.

The Sclerotinia advisory program was evaluated in several fields with a history of yield losses to the disease in 1994 and 1995. Based on its success in providing an early warning of favorable conditions for disease onset at multiple locations, the program was released to growers in 1996. Over the past 2 years, treatments with

iprodione at 1.12 kg/ha according to the advisory resulted in a yield, gross value, and net return that were similar to those of the recommended "demand" program (Table 3). The demand program relies on intensive scouting at weekly intervals for early detection of disease onset. This program recommends the first application of fungicide when the initial symptoms and signs of disease are detected in a field. Thereafter, sprays are recommended at 4-week intervals until 10 days prior to harvest. A major pitfall in this approach has been the failure of many growers to detect disease at initial onset and prior to the occurrence of heavy crop damage. To be effective, the demand program requires weekly scouting of fields for early detection of disease. The disease warnings pro-

vided by the Sclerotinia advisory at or just prior to disease onset are expected to be a valued resource for growers and consultants to maximize the efficiency of scouting and disease management.

Frost advisory. Historical records of low temperatures at the 30-cm level aboveground in peanut fields were used to develop algorithms that adapt forecasts by the National Weather Service to sites in the peanut production area of Virginia (22). The 7-day low-temperature forecasts for local airports from the National Centers for Environmental Prediction were selected as possible predictors of minimum temperatures in peanut fields. Using historical records, it was found that the low-temperature forecasts for Byrd International Airport in Richmond were most highly correlated with actual low temperatures at three regional sites in the peanut production area of Virginia.

The Virginia Peanut Frost Advisory Program uses a separate algorithm to adapt the 7-day low-temperature forecast to each regional site in the peanut production area. The 7-day forecast is obtained at approximately 7:30 A.M. daily over the Internet and used as input to algorithms for developing frost advisories. R^2 values indicated the best accuracy occurred in predictions for day 1, followed by good levels of accuracy in day 2 through day 4 forecasts across all three regional sites (Table 4). A sharp reduction in R^2 was noted in predictions for day 5 through day 7, which indicated a low degree of accuracy. These forecasts lacked accuracy primarily in predicting the actual day in which cold or warm air masses entered the regions, but they were still useful in developing a harvest plan to avoid a high risk of frost or freeze damage. Warnings for frost, freeze, and hard freeze conditions are issued when the adjusted low-temperature forecast in a region is 2.7°C (37°F) to 0.5°C (33°F), zero (32°F) to -1°C (30°F), and <-1°C, respectively. In addition to low temperatures, the advisory also reports the probability of precipitation, mean cloudiness, and mean wind speed for periods up to 192 h.

Heat units and weather summaries.

Temperature and rainfall are important environmental factors in the growth and development of peanut. Several attempts have been made to utilize temperature for prediction of crop maturity. Using a heat unit method, Emery et al. (6) estimated that a base temperature of 13.3°C (56°F) could be used to determine the heat unit requirements of Virginia-type cultivars. During the last two decades, peanut growers in Virginia have used heat unit reports and rainfall to gauge the seasonal effects of weather on maturity. Heat unit determinations for peanuts in Virginia are routinely started on 1 May, when much of the crop is planted. A maximum temperature of 35°C (95°F) is used whenever temperatures are

Fig. 5. Daily risk indices (DRI) and algorithm for Sclerotinia blight advisory. Moisture = 1 if RH $\geq$ 95% for $\geq$ 8 consecutive hours on a given day, or rainfall $\geq$ 1.27 cm over previous 5 days or $\geq$ 2.54 cm over previous 10 days, otherwise index = 0. Soil temperature = 3, 2, 1, or 0 if daily averages at 10-cm depth were $\leq$ 22, $\leq$ 25, $\leq$ 28, or $>$ 28°C, respectively. Vine growth = 3, 2, or 1 if vines overlapping between rows, $\leq$ 15 cm from overlapping, or $>$ 15 cm from overlapping, respectively. Canopy = 3, 2, or 1 if $\geq$ 95, $\geq$ 75, or $<$ 75% of soil shaded by foliar canopy. Five-day index (FDI) = sum of DRI values over previous 5 days.

Table 4. Relationship (R^2) of predicted and actual minimum temperatures over the 4-year period (1992 to 1995) of producing 7-day forecasts for the Virginia Peanut Frost Advisory Program

Day ^y	Location ^z		
	Suffolk	Capron	Waverly
1	0.74	0.77	0.80
2	0.64	0.65	0.68
3	0.63	0.62	0.62
4	0.57	0.57	0.53
5	0.39	0.41	0.39
6	0.29	0.26	0.27
7	0.17	0.17	0.18

^y Each day was labeled by counting into the future, with zero being the day a forecast was issued.

^z R^2 values for each day and location were significant at $P \leq 0.01$.

$\geq 35^{\circ}\text{C}$. Prior to 1995, daily heat units for peanuts were determined by averaging the maximum and minimum temperature and subtracting the base temperature of 13.3°C . With the availability of data collected at 15-min intervals by electronic sensors at multiple sites, heat unit determinations are currently made by records of hourly average air temperature. Using this method, daily heat units = $\Sigma [(\text{avg. hourly temperature} - 13.3^{\circ}\text{C})/24]$, where 35°C is used when the average hourly temperature is $>35^{\circ}\text{C}$. Peanuts generally reach maturity upon accumulation of 1,316 to 1,371 heat units (2,400 to 2,500 Fahrenheit units) in years without prolonged moisture stress during the period from flowering to pod set. This critical period normally begins about 1 July and may extend into August.

Growers have always been interested in records of air and soil temperature and rainfall. Daily weather summaries are especially useful in the spring to determine when soil temperatures are favorable for soil fumigation to control *Cylindrocladium* black rot. These records are also used to determine when soil temperatures are favorable for planting peanuts and cotton. During the growing season, these data can be helpful in determining the optimum rates of certain herbicides and in troubleshooting problems with performance of pesticides.

Weather Monitoring Networks

Peanut growers in Virginia were among the first in the nation to adopt weather-based advisories for making disease management decisions. In 1978, an agro-environmental monitoring system (AEMS) was developed at Virginia Polytechnic Institute & State University through grants from the National Aeronautic and Space Administration and the U.S. Department of Agri-

culture (18). Initially, the system included seven weather stations, with two located in the peanut production area. Each station was equipped with electronic sensors and microprocessors to collect data at 10-min intervals. A computer at Virginia Tech downloaded and processed the data from each field station daily through telecommunication links with modems. These data were used to explore application programs in irrigation, crop growth, and disease forecasting. In 1981, two weather stations were used to implement an early leaf spot advisory program (15) and to provide heat unit reports for peanut. Because of the immediate success of these programs, a third AEMS station was moved to the peanut production area in 1983. Continued research in model development resulted in the release of an improved leaf spot advisory in 1989 (3), a frost advisory in 1992 (22), and a Sclerotinia blight advisory in 1996 (14).

While the AEMS system offered some of the most advanced technology in electronic weather monitoring through the 1980s, the system was expensive to operate and required the full-time attention of a technician for operation and maintenance. Problems experienced with AEMS stations included the sensitivity of equipment to power surges during thunderstorms, the limited memory capacity for data storage, and the inability to provide on-site access to data. Evaluations of the EnviroCaster (Neogen Corp., Lansing, MI), a solar-powered weather monitor, were initiated in 1989 to alleviate some of these problems and address the desire of growers to have at least one monitor in each county. Through cooperative work with the Neogen Corp., the EnviroCaster was programmed to provide disease advisories and heat unit reports for peanuts.

EnviroCaster units were located at sites with managed turf in close proximity to peanut fields (Fig. 6). The monitors and sensors were not placed in peanut fields because of spatial incompatibility with crop management practices. The units were equipped with sensors to monitor air and dew point temperatures at 30 cm above ground level, soil temperature at a 5- and 10-cm depth, and rainfall at 15-min intervals. Inside the weatherproof cabinet, an LCD screen and printer provided ready access to weather data and crop advisory models (Fig. 6). The ease of data access, coupled with a user-friendly operating system, solar power supply backed up by two 9-volt batteries, printer, and memory for storage of up to 20 days of data, were distinct advantages over AEMS stations. After 2 years of successful testing, the Virginia Agricultural Council purchased two EnviroCaster units in 1991 for on-farm demonstration and evaluation by the Virginia Cooperative Extension. Following the success of these trials, 10 additional units were purchased through contributions from the Peanut Soil and Water Conservation District, peanut companies, the Virginia Farm Bureau, chemical and fertilizer companies, and growers. At the end of the 1994 growing season, technical expertise for maintaining the AEMS system was lost when the USDA unit at the Tidewater Center was closed. Beginning in 1995, AEMS operations were phased out and the EnviroCaster became the sole source of data for weather-based crop management programs.

The location of EnviroCaster units was coordinated with county agents and growers to create a network of stations that offered timely weather-based crop information and advisories of value to the peanut industry in Virginia (Fig. 7). At each

Fig. 6. (Top) Typical site and setup of EnviroCaster for collecting weather data. (Bottom) Keypad, LCD display, and printer for on-site access to weather summaries and advisory models.

Fig. 7. Peanut production counties in Virginia and EnviroCaster sites (Δ, ☆) in the weather monitoring network (☆ denotes regional weather sites).

site, the EnviroCaster was placed approximately 30 m from the telephone in the farm cooperator's shop. Communications were established through a modem and RS-232 cable to the EnviroCaster. A telephone line sharing device, ASAP TF-505 (Command Communications, Inc., Aurora, CO), was used to allow multipurpose use of the telephone line with minimal inconvenience to the cooperator. Surge protectors were installed on lines to all equipment.

A data collection and processing computer at the Tidewater Center was programmed to automatically retrieve, archive, and process data from each EnviroCaster and then transmit daily weather and advisory information to a computer dedicated to information delivery. This process begins daily at 1 A.M. and is completed at approximately 2:30 A.M. Data collection and processing are performed using Microsoft Visual Basic Version 3.0 (Microsoft Corp., Redmond, WA) and Norton pcAnywhere (Symantec Corp., Cupertino, CA) to execute specific functions at designated times. A data archive is updated daily and maintained on an external 230 MB optical cartridge drive.

Information Delivery

As part of the grower survey in 1990 and 1991, a section was included to identify the programs and resources that impact on management decisions concerning the use of pesticides in peanuts. Survey participants indicated that the Peanut Production Guide, the leaf spot advisory program, and sponsored events by Virginia Cooperative Extension were primary sources of information for decisions in crop management (Table 5). Only a small percentage of growers reported the use of private consultants. The frost advisory and Sclerotinia blight advisory were developed subsequent to this survey, thus use of these programs was not included. Overall, the survey results confirmed the important role of extension programs in providing growers with information and guidance for making crop management decisions.

Publications. Traditional methods of information delivery have included publications, production meetings, on-farm demonstrations, and farm tours. Newsletters sent usually every 2 or 4 weeks to growers by county extension agents have been relied on for updating crop management recommendations. These letters can be 7 days or longer in reaching clientele, and therefore content usually emphasizes calendar-based inputs. Crop production guides and other extension publications, which are updated annually, also focus on calendar-based inputs since they must be prepared up to 3 months in advance of distribution and up to 6 months before the crop is planted. While useful as a general guide for crop management, these publications can lack recent changes in pesticide registrations and use patterns. The information may also lack relevance to prevailing crop conditions and not make the best use of cost-saving, site-specific integrated pest management (IPM) strategies.

Telephone recordings. The toll-free telephone hot line at the Tidewater Center has been the most widely used method for delivering up-to-date advisories since the leaf spot advisory was first introduced in 1981. This hot line delivers regional advisories that are based on weather data collected by three regional weather monitors (Fig. 7). The hot line has logged as many as 4,000 calls each growing season from 1 June until completion of harvest. This method of delivery has ensured the timeliness of updates and made them accessible 24 h a day including weekends. In 1995, the hot line at the Tidewater Center logged 2,031 calls. The reduced number of calls in 1995 may be attributed to county agents issuing local advisories as recordings on county-wide hot lines. These advisories were prepared from data collected by the peanut weather network and obtained by county agents directly through the Peanut/Cotton InfoNet. Although effective for delivery of county and regional advisory updates, recordings do not offer an efficient means to report the output of several advisory programs across multiple locations.

Radio and television. Radio broadcasts of telephone recordings have been used annually as an additional means to deliver regional leaf spot advisories and pest alerts since 1981, frost advisories since 1992, and Sclerotinia blight advisories in 1996. This approach has provided an effective means to promote advisory programs and improve the timeliness of program outreach. Limits on the length of messages did not pose a significant problem until additional programs and weather stations were added. Another problem has been the failure of some broadcasters to update the advisory reports daily, including weekends. From 1982 to 1985, the leaf spot advisory was also broadcast by a television station in eastern Virginia. As part of the 7:15 A.M. and 6:15 P.M. weather reports, the advisory program became well-known throughout the region. However, these broadcasts were not offered on weekends and were discontinued after changes in personnel at the station.

Electronic bulletin board. The Peanut/Cotton InfoNet is an electronic bulletin board system that was created in 1995 for delivery of advisories and weather data from all locations in the weather monitoring network (4). Cotton information was incorporated into the system because of its increasing importance in the region. The software, Wildcat! Version 4.0 (Mustang Software, Inc., Bakersfield, CA), provides a user-friendly menu and operating system. The main menu provides access to a files menu with options for viewing and downloading files to the user's computer. To maintain data integrity and a virus-free environment, users cannot upload or alter files on the InfoNet. First-time users are asked to enter their address, profession, age, telephone number, and a password. In addition to this information, the system maintains a record of the time and date of calls by each user.

The Peanut/Cotton InfoNet can be accessed from 15 March until 15 November with a personal computer and modem through a local number (657-9727), in-state toll-free number (1-800-479-9727), or out-of-state long distance number (1-757-657-9727). Communication software should be set at 9,600 to 19,200 BAUD, ANSI terminal emulation, ZMODEM transfer protocol, EIGHT bits per character, ONE stop bit, and NONE parity. Through daily uploads of files by the data processing computer, timely advisories and weather summaries are made available throughout a growing season. Included are early leaf spot advisories, Sclerotinia blight advisories, peanut and cotton heat unit reports, and daily weather summaries (max./min./avg. air temp., avg. soil temp., rainfall). Cotton heat units are determined in a manner similar to those of peanut, but with a base temperature of 15.6°C (60°F). Weather summaries and crop advisories are filed on the InfoNet according to location

Table 5. Programs and resources used by growers to make management decisions concerning pesticide use on peanuts in 1990 and 1991^y

Program/resources	Growers surveyed (%)	
	1990	1991
Sponsored events ^z	100	100
Peanut Production Guide	100	97
Leaf spot advisory	94	91
Plant diagnostic clinic	23	16
Nematode assay	13	6
Private consultants	9	9
No. of growers surveyed	35	32

^y Data are the percentage of growers surveyed who used each program or resource to improve the efficiency of crop management.

^z Sponsored events are annual production meetings, field days, and short courses offered by the Virginia Cooperative Extension.

and month. Corn earworm advisories (7) are filed separately and uploaded weekly to the InfoNet from June through September. These advisories report weekly moth counts from up to 19 black-light traps and provide warnings to scout peanut, soybean, and cotton for this pest. Regional frost advisories are prepared and uploaded daily at 7:30 A.M. from 25 September until completion of peanut harvest.

The Peanut/Cotton InfoNet is proving to be an effective means for expanding the timely outreach and scope of advisory programs for crop management. County agents in the southeast district used the Peanut/Cotton InfoNet from planting to harvest in 1995. All segments of the peanut industry were given access to the system subsequent to demonstrations at field days starting 24 August 1995. Sixty users,

ranging in age from 11 to 60, logged onto the system from 1 May to 10 November. According to system records, the average user age was 39. A total of 948 calls was received, and the system processed 1,678 downloads of files. The greatest number of users was associated with industry and research groups, but county extension agents were the most frequent users.

Future Considerations

Part of the mission of land-grant universities is (i) to create knowledge, (ii) to test its validity, (iii) to preserve information, and (iv) to transmit relevant information to clientele. An ongoing challenge for extension is to continually improve the outreach, relevance, and timeliness in delivery of information. In the case of programs such as the leaf spot, Sclerotinia blight, and

frost advisories for peanuts, there must be open avenues for program output to reach county agents and growers on a daily basis. Telephone hot lines, radio broadcasts, and television broadcasts can fulfill only part of this need. Another approach is to use electronic systems such as the Internet, but many rural communities are limited to only long-distance telephone access. Implementation of electronic bulletin board systems, such as the Peanut/Cotton InfoNet, provides an alternative means for delivering timely information at minimal cost. This system, along with the Peanut/Cotton Weather Network, was created through the cooperative efforts and support of growers, consultants, agribusiness companies, farm organizations, government agencies, and Virginia Tech. The development of peanut production and advisory models, coupled

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with advances in weather monitoring and other communications technology, is offering new opportunities for extension programs to better serve the needs of agriculture. These advances in technology are expected to have an important role in sustaining the peanut industry through present and future uncertainties in the market demand and pricing of peanuts in the United States.

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