Chapter 12

APPLICATIONS OF EXPERT SYSTEMS IN PEANUT PRODUCTION

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INTRODUCTION

An old African proverb states, "When an old man dies, a library burns" (Barrett and Jones, 1989). Experts gain knowledge through research and experience. Their expertise is vital to future success and must be perpetuated in a timely manner. A specific type of computer software called an expert system (ES) enables a computer to mimic the diagnosis and decisions of human experts. The specialized computer programs use a pool of information or "knowledge base" expressed as if-then rules formulated from the knowledge of human experts. New knowledge can be incorporated into the ES by formulating new rules. This is similar to humans learning from experience. An ES offers many advantages in making complex decisions in that it not only makes the expert decision, but can provide the user with the reasons for the decision and assign a probability reflecting the accuracy of the recommendation.

Foley (1987) concluded that most of the ES development is occurring behind closed doors in Fortune 500 companies. Major developers are defense contractors, electronics corporations and large manufacturers. According to Gill (1992), failures of many ES could be traced to poor implementation rather than technical issues. ES have been slow to develop in agriculture partly due to the need for multi-disciplinary teams of experts and partly due to the perception that computer technology is not widely accepted in traditional agriculture. Smith *et al.* (1988) studied 12 farmers to evaluate the perceptions and acceptance of ES. They concluded that ES increase a farmer's confidence in his own management decisions 91% of the time, because they provide another knowledgeable source of information. Gum and Blank (1990) compared ES to standard extension programming approaches and concluded that ES have greater educational impact than traditional methods and are more cost effective. COMAX helps cotton producers decide when to irrigate and apply various chemicals throughout the year (McKinion and Lemmon, 1985; Lemmon, 1986; McKinion *et al.*, 1988). It is used on a relatively widespread basis in Texas and Mississippi. Other ES for other phases of crop production have met with little or no acceptance (Batchelor *et al.*, 1988; Lacey *et al.*, 1989; Meyer *et al.*, 1991; Nevo *et al.*, 1991).

Advisories pertinent to peanut production have been developed and released during recent years. These advisories are similar to expert systems in that they provide expert advice based upon if-then rules. Most have been directed toward improving the control of early (*Cercospora arachidicola* Hori) and late [*Cercosporidium personatum* (Berk. et Curt.) Deighton] leaf spot in peanuts. These advisories for fungicide application in Virginia (Cu and Phipps, 1993) and North Carolina (Bailey *et al.*, 1994) currently are used by approximately 70% of Virginia farmers and 50% of North Carolina farmers. Other advisories implemented in the Southeast (Nutter and Culbreath, 1991; Davis *et al.*, 1993) are gaining popularity.

Throughout peanut production, harvesting, marketing, and processing, numerous decisions are made affecting economic returns, yield, quality, and product safety in the human diet and their subsequent effects on the environment. Decisions require knowledge from several areas of scientific expertise and peanut related industries such as crop and soil science, entomology, engineering, pathology, food science, economics, production, marketing, and processing. The combined scientific disciplines are not separate entities during peanut production but are interrelated through complex processes. Ten ES designed to aid decision making in all phases of the peanut production, marketing and processing system include:

1. PNTPLAN: A whole farm management system for planning,
2. TILNUT: A tillage and land preparation management system,
3. EXNUT: An irrigation management system,
4. DRYNUT: A nonirrigated peanut production management system,
5. MNUT: A marketing management system,
6. HARVPRO: A harvesting management system,
7. PECMAN: A curing management system,
8. STORNUT: A storage management system,
9. SHELNUT: A shelling plant management system, and
10. VNUT: A variety evaluation system.

The objective of this chapter is to provide basic information on the first seven ES that form an integrated farm management system shown in Fig. 1. General information common to all the systems is followed by specific information about each system.

GENERAL INFORMATION

Design

The seven ES are designed to operate independently of each other, as well as collectively, as shown in Fig. 1. Most systems are designed to run on an MS-DOS compatible computer with two floppy disk drives or a hard drive and 640K of RAM (random access memory). Generally, the sequence in developing each ES is to (a) develop a knowledge base from accumulated data and experts in research, extension, and industry; (b) develop flow charts for a specific time frame showing "if-then" decisions that must be made; (c) program the "if-then" decisions; (d) validate and compare the system's performance with management by experts and conventional management

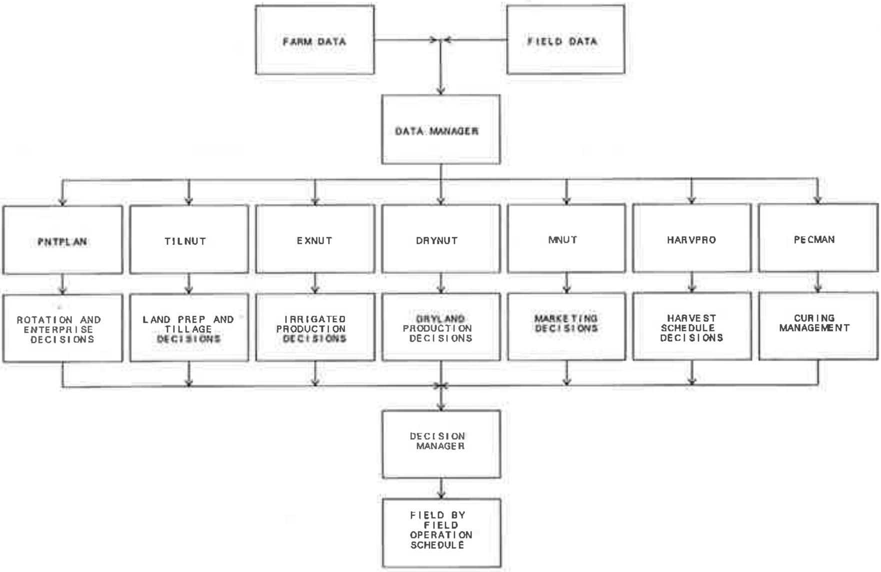

Fig. 1. Organizational chart for farm management system for peanuts.

systems; and (e) repeat steps 2-4 as required to meet the needs of the user. Users may review the written knowledge bases, flow charts, and specific if-then decisions prior to their use of each system. These systems are meant to assist the users in their production decisions. The choice of using the recommendation relies solely on the user. This is similar to the grower accepting or rejecting advice from a consultant or county extension agent.

Different versions of each ES are needed to accommodate the variations in environment, pests, and recommended practices in the different peanut production regions of the U.S. These versions are identified according to the following 10 designated growing regions: Alabama; Florida; Georgia; North Carolina; east and west Oklahoma; central, south, and west Texas; and Virginia.

Standard definitions of terms and concepts are consistent with those listed elsewhere in this book and those pertaining to yield, crop loss, and diseases are as recommended by Nutter *et al.* (1993).

Knowledge Bases

Generally, the written knowledge bases describe the relationship between inputs and outputs and the management strategies to optimize the system outputs for each time frame. Typical inputs include financial, plant, soil, weather, pest, and regulatory variables. Typical outputs include economic returns, yield, seed, milling, and edible quality as well as environmental enhancement. The knowledge bases contain the latest research findings as reported in this book with additional knowledge and information on the relationship of inputs to outputs.

The seven ES use many of the same input and output variables to address the different industry problems. Thus, to avoid repetition, a set of generic data requirements have been established for running and validating the programs (Tables 1, 2, and 3). Each program requests minimum input data to make the desired recommendation. Some general information follows on crop rotation data, scouting, pesticide application requirements, time frames, scouting equipment, soil temperature, leaf spot, varieties, and soil classes.

Crop rotation is a very important input for each ES. For the ES presented here, decisions are based upon data gathered from 496 cooperating farms in the Southeast from 1981 through 1992. Lamb *et al.* (1993) concluded from these data that the decrease in peanut yield in the Southeastern U.S. was related to changes in crop rotation; and that yield, quality, and economic returns could be improved substantially by using these ES. An integral component of this data set was the relationship of outputs (such as peanut yield, quality, and economic returns) to both the length and suitability of a crop rotation sequence. Some of these data are summarized in Fig. 2 and Table 4. The ES use crop rotation and scouting as primary tools in pest management to maximize yield, quality, and economic return while minimizing

Table 1. Historical field data required by one or more expert systems for peanut production and marketing management.

Required data	Expert system[a]						
	DRY	EXN	HAR	MNU	PNT	TIL	PEC
Farmer/field ID	X	X	X	X	X	X	X
Number hectares	X	X	X	X	X	X	
Equipment list			X		X	X	X
4-Year crop rotation	X	X	X	X	X	X	
Peanut yield history	X	X	X	X	X	X	
Yield potential	X	X	X	X	X	X	
Soil type	X	X	X	X	X	X	
Slope	X	X		X			
Irrigated/nonirrigated	X	X	X	X	X	X	
Irrigation capacity		X			X		
Irrigation type		X			X		
Max. irrigation and rainfall without runoff	X	X		X		X	
Pest history	X	X	X	X		X	
Previous crops, pesticide history	X	X					
Winter cover crop	X	X			X	X	
Grazing data	X	X			X	X	
Fallow	X	X		X	X	X	
Subsoiling date, depth	X	X		X		X	

[a]Expert systems identification: DRYNUT (DRY) - Management of nonirrigated production, EXNUT (EXN) - Management of irrigated production, HARVPRO (HAR) - Harvest date scheduling, MNUT (MNU) - Prediction of yield and quality, PNTPLAN (PNT) - Multi-year whole farm planning, TILNUT (TIL) - Management of tillage and land preparation, PECMAN (PEC) - Management of curing systems.

pesticide use and negative environmental impact.

After planting, fields must be scouted by a competent consultant or properly trained scout on a regular (at least weekly) basis. Even if a scout or consultant is hired, the grower is encouraged to learn scouting techniques and effective application of pesticides.

Table 2. Current crop data required by one or more expert systems for peanut production and marketing management.

	Expert system[a]						
Required data	DRY	EXN	HAR	MNU	PNT	TIL	PEC
Expected market price (quota & additional)				X	X		
Fall or preplant soil test data	X				X		
Fertilizer application	X	X			X	X	
Land preparation	X	X			X	X	
Lime application	X	X			X	X	
Landplaster application	X	X			X		
Row spacing	X	X	X			X	
Seedbed width and height	X	X				X	
Variety	X	X	X	X	X	X	
Germination	X	X				X	
Seed count/kg	X	X				X	
Planting date	X	X	X	X		X	
Seeding rate	X	X		X	X	X	
Planting depth	X	X				X	
Row direction	X	X		X		X	
Soil moisture at planting	X	X		X		X	
Emergence rate	X	X				X	
Emergence date	X	X				X	
Post-plant soil test data	X	X					
Hardpan test data	X	X				X	
Preplant pesticide application data	X	X	X	X	X	X	
Date	X	X	X	X		X	
Days after planting (DAP)	X	X	X	X		X	
Percent canopy	X	X	X	X			
Scouting reports	X	X	X	X		X	
10.2 cm (4") max-min soil temperatures	X	X	X	X		X	
Weather forecasts (rain, hurricane, frost)	X	X	X	X		X	X
Max-min air temperature	X		X	X			X
Rainfall	X	X	X	X		X	
Irrigation		X	X	X		X	
Fruiting data	X	X	X	X			
Pesticide application data	X	X	X	X	X	X	
Pod maturity profile	X	X	X				X

[a]Expert systems identification: DRYNUT (DRY) - Management of nonirrigated production; EXNUT (EXN) - Management of irrigated production; HARVPRO (HAR) - Harvest date scheduling; MNUT (MNU) - Prediction of yield, quality, and price; PNTPLAN (PNT) - Multi-year whole farm planning; TILNUT (TIL) - Management of tillage and land preparation; PECMAN (PEC) - Management of curing systems.

Table 3. Validation data required for one or more expert systems for peanut production and marketing management.

Required data	Expert system[a]						
	DRY	EXN	HAR	MNU	PNT	TIL	PEC
Digging date	X	X	X	X			X
Combining date	X	X	X				X
Maturity data	X	X	X	X			X
Yield	X	X	X	X	X	X	
Area grade data	X	X	X	X	X	X	X
Sample for evaluation	X	X	X	X		X	X
Pest evaluation	X	X	X	X		X	
Harvest loss	X	X	X	X		X	

[a]Expert systems identification: DRYNUT (DRY) - Management of nonirrigated production; EXNUT (EXN) - Management of irrigated production; HARVPRO (HAR) - Harvest date scheduling; MNUT (MNU) - Prediction of yield, quality and price; PNTPLAN (PNT) - Multi-year whole farm planning; TILNUT (TIL) - Management of tillage and land preparation; PECMAN (PEC) - Management of curing systems.

Table 4. Typical data relating crop rotation to peanut quality[a].

Crop rotation[b]	Grade (SMK+SS)[c]	Jumbos	Germination	Aflatoxin
	----------	%	----------	ppb
0	68.3	10.2	80.2	19.3
1	71.1	14.7	78.1	38.8
2	73.0	17.1	83.0	86.1
3	72.4	16.5	83.6	27.1
4	72.6	25.5	86.0	16.8

[a]Each quality value represents the mean for eight to 131 fields that were surveyed, depending on the availability of data.

[b]Crop rotation is the number of consecutive years since a legume was planted.

[c]Sound mature kernels and sound splits.

All ES emphasize the safe and proper pesticide use as recommended in the latest state extension pest control handbook (e.g., Delaphane, 1994). Users are encouraged to comply with label directions and precautions to protect the applicator and the environment. If desired, the expert farm management system will maintain chemical records required by the state and/or regulatory agencies.

The time frame parameters used in most of the peanut ES are (a) prior to planting, (b) planting-to-emergence, (c) emergence-to-fruit initiation (FI), (d) primary-fruiting, (e) maturation, (f) harvest, and (g) marketing. Based on the current data and the time frame, the ES prompts the user for inputs

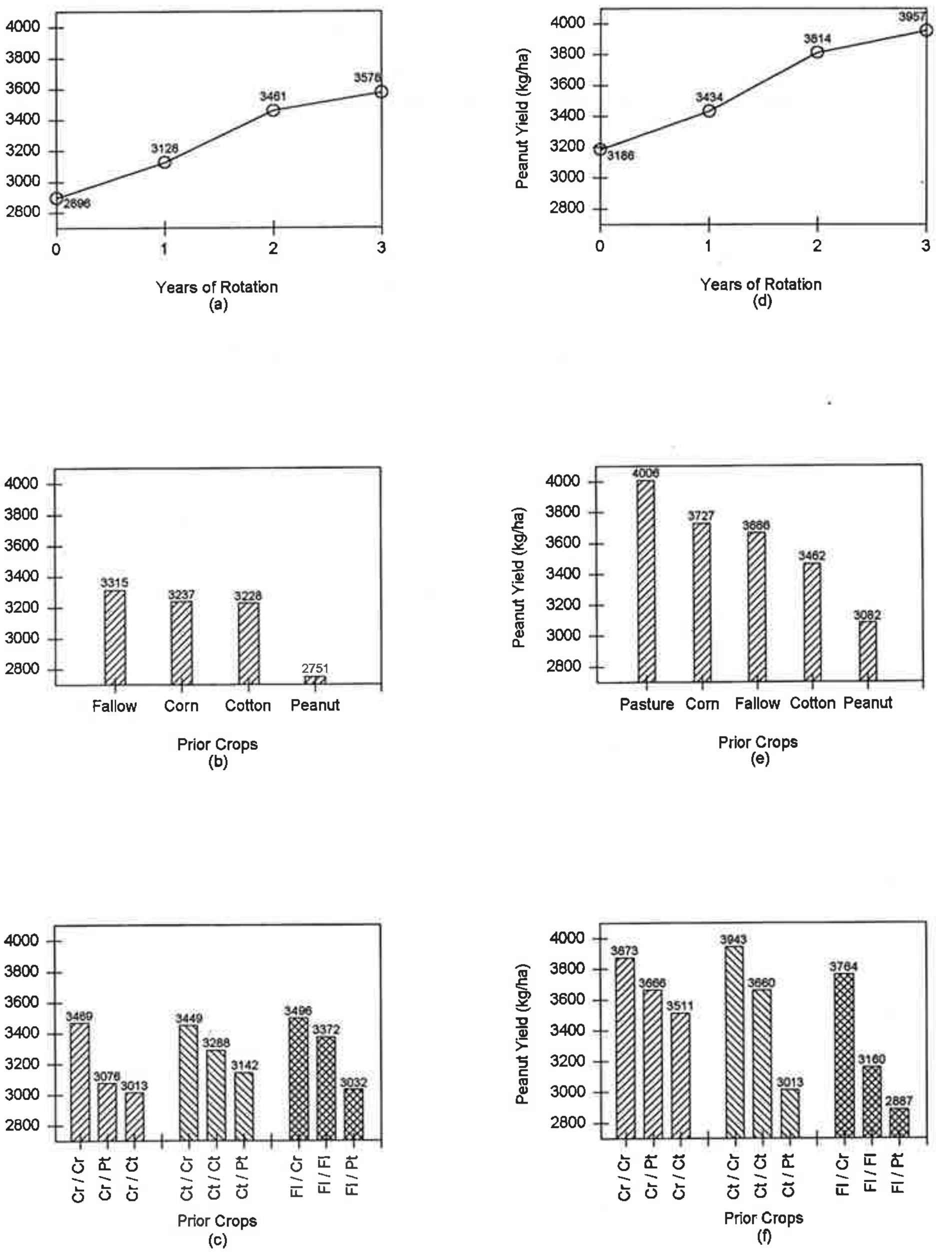

Fig. 2. Peanut yield versus crop rotation. (a) Peanut yield versus year of rotation (nonirrigated), (b) peanut yield versus prior crop (nonirrigated), (c) peanut yield versus 2 years prior crop sequence (nonirrigated), (d) peanut yield versus years of rotation (irrigated), (e) peanut yield versus prior crop (irrigated), and (f) peanut yield versus 2 years prior crop sequence (irrigated).

needed for decisions. The first time an ES is used, most of the information is provided by the user under a field (and farm) name and will not have to be entered again.

Many of the ES require that the scout and/or farmer be familiar with the emergence date and various stages of plant development as well as fruit initiation (FI) dates. Accuracy must be maintained for the system to work properly. Emergence date is defined as when a 90% stand has been established. Replanting is recommended if seedling emergence is less than that adequate to produce the attainable yield potential. Emergence to FI, primary fruiting and maturation stages are calculated from a FI date. FI is the date the first flush of blooms occurred that produced an average of 10 fruit indicators (pegs + pods) per plant within 8 days. The ES calculate the FI date using the following formula:

$$X = Y - 8 - \frac{(P_e + P_o) - 10}{2} \qquad \text{(Eq. 1)}$$

X = FI date,

Y = Date field was observed,

P_e = Average number of pegs per plant [in this case, a peg is any visual growth of the gynophore (pin or peg) above or below the ground], and

P_o = Average number of pods per plant.

Many of the ES require the following scouting equipment: (a) large-mouth rain gauges, (b) a penetrometer rod, (c) a posthole digger, (d) a maximum-minimum soil thermometer, and (e) a digital thermometer for calibration.

The scout must determine the effective water which includes both irrigation and rainfall measured by the rain gauge minus the runoff. When runoff occurs, effective water can be estimated or determined by digging holes in representative areas of the field 24-48 hours after rainfall or irrigation. In dry sandy soils (Group I), 2.5 cm of effective water will wet the soil down to 46-61 cm. In dry, medium to heavy soils (Groups II, III and IV), the 2.5 cm of effective water will wet the soil to approximately 30 cm.

The penetrometer consists of a 1.27-cm diameter steel rod 91.4 cm long with a tip tapered at 19° and a 22.9-cm long handle made from 1.27-cm schedule-40 pipe. If the moisture is near field capacity and the penetrometer does not penetrate the soil in more than 50% of the locations checked when an 800 N (180 lb) force is applied, then a hardpan exists that restricts peanut root growth and development. The ES will make recommendations to alleviate the hardpan or to minimize its effect and environmental impact.

Posthole diggers are required only when runoff occurs or when abnormal field conditions cause poor root systems. The peanut root system will generally develop laterally and vertically to a depth of approximately 120 cm. The root system profile can be determined by digging holes within and between rows. The ES use research information as illustrated in Fig. 3 to obtain a deep healthy root system.

The maximum-minimum soil thermometer indicates the current and extreme soil temperatures in the geocarposphere (GCS) since the last

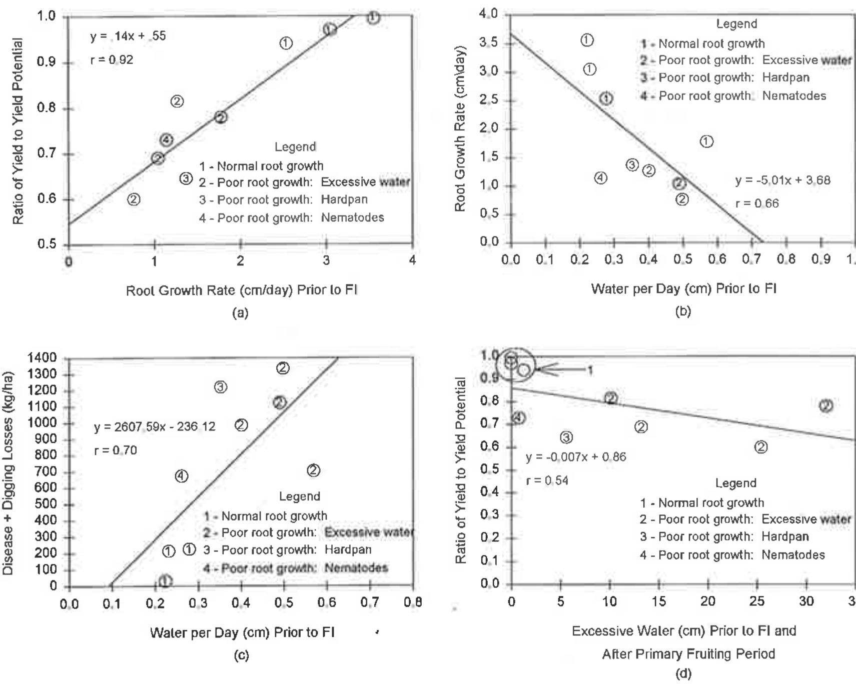

Fig. 3. Typical research data included in expert systems to obtain optimum plant health. (a) Ratio of yield to yield potential versus root growth rate prior to FI, (b) root growth rate versus water per day prior to FI, (c) disease and digging losses versus water per day prior to FI, and (d) ratio of yield to yield potential versus excessive water prior to FI and after primary fruiting period.

recording. The thermometer should be the weatherproof type, with a 10 cm long stem, and maintain accuracy of at least ±1 C.

The digital thermometer has a 10-cm long probe and is used to calibrate the maximum-minimum thermometers. Accuracy of the unit should be ±0.25 C.

Since 1981, research at the National Peanut Research Laboratory, Dawson, Georgia, has proven that the maximum-minimum soil thermometer is the best indicator for determining when soil temperature is optimum for planting, root growth, fruiting, maturation, pest control, and when the plant is stressed by drought or pests (Davidson *et al.*, 1991). Typical relationships of the maximum soil temperature during the major fruiting period to actual yield, market grade, aflatoxin percentage, shelling outturns, and seed germination of commercial fields are shown in Figs. 4 and 5. These ES use soil temperature data as an aid to selecting planting dates, alerts for scouting for root and pest problems, irrigation scheduling, and to indicate yield and quality potential.

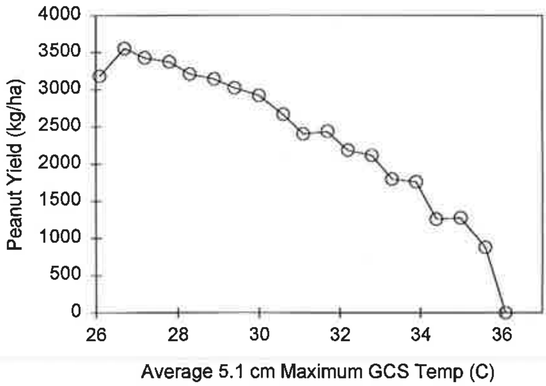

Fig. 4. Typical relationship of maximum geocarposphere temperature to peanut yield, n = 732.

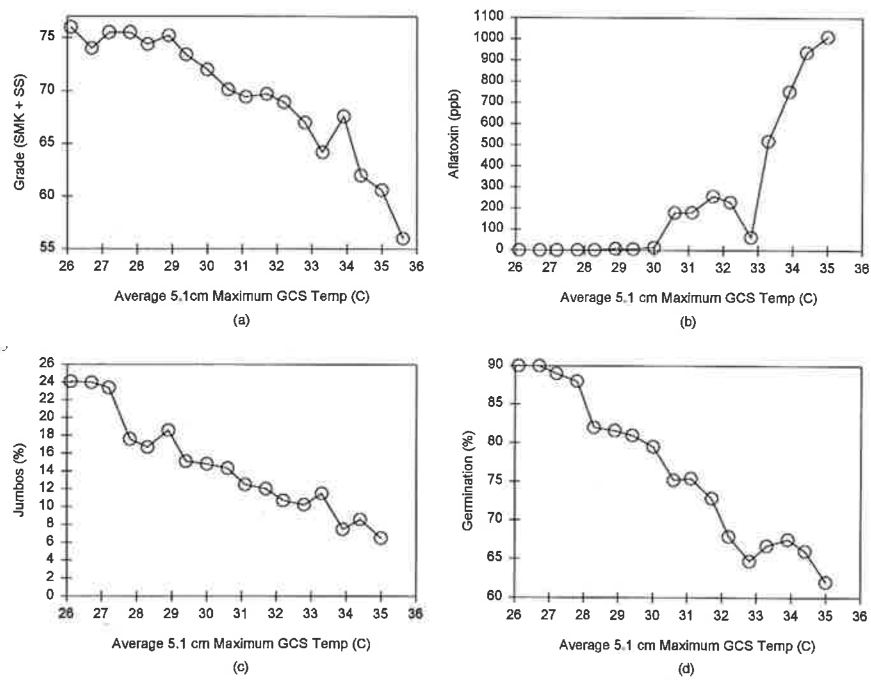

Fig. 5. Typical relationship of maximum geocarposphere temperature to peanut quality. (a) Farmers stock grade (SMK+SS), n = 516; (b) aflatoxin (ppb in oil stock), n = 408; (c) percent jumbos (ride 8.33 x 11.05 mm slotted screen), n = 415; and (d) percent germination, n = 415.

The maximum soil temperature underneath the canopy will generally be below 28.9 C if the plant covers more than 90% of the soil and the plant is not experiencing stress (Davidson *et al.*, 1991). For partial canopy, (less than 90%), this maximum temperature will generally be below 31.1 C during the fruiting period. Cylindrocladium black rot (CBR) is slowed when soil temperature exceeds 25 C and stops if temperatures exceed 35 C (Sidebottom and Beute, 1989). Recent unpublished research indicates that *Sclerotinia minor* also becomes very active when maximum soil temperature drops below 26.7 C. Research data (Davidson *et al.*, 1991) also indicate that *Rhizoctonia solani*, pod rot, southern corn rootworm, and other wet-weather pests reach threshold levels when the maximum soil temperature is below 26.7 C for more than 11 degree days (Fig. 6). White mold is a high temperature pest, but it can become significant at maximum soil temperatures below 26.7 C if minimum soil temperatures are above 21.1 C. Degree days are defined as the cumulative degrees that the maximum daily soil temperature was below 26.7 C. For example, if maximum soil temperature was 24.7, 25.7, 26.7, and 27.8 C for 4 consecutive days, then degree days would be 2 C + 1 C + 0 + 0 = 3 C . Except for white mold, the potentially damaging levels for these pests also occur when minimum soil temperature is below 21.1 C for several days. Daily maximum and minimum soil temperatures rise and fall gradually; therefore, daily temperatures can be estimated by linear interpolation between days for which data are unavailable. Data for ES should be collected daily or every other day when undesirable degree days are accumulating. The programs provide a pest alert for intensive scouting and/or possible pesticide applications as well as making recommendations to irrigate, or to withhold irrigation, to prevent the accumulation of undesirable degree days. Plant stress during fruiting resulting from excessive water, drought, or soil-borne diseases are generally minimized if the maximum geocarposphere temperature underneath the canopy is between 26.7 and

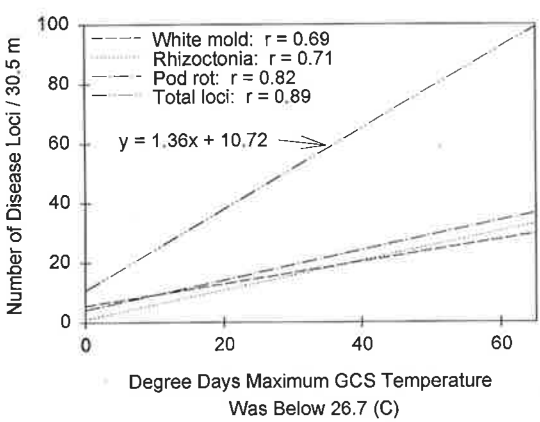

Fig. 6. Typical relationship of maximum geocarposphere temperature to impact of low temperature pests.

28.3 C. After fruiting, assuming that the maximum 5.1 cm soil temperature does not exceed 29.4 C the risks will be minimized for high temperature pests (Fig. 7) (Davidson *et al.*, 1991). Such high temperature pests include *Aspergillus* crown rot, *A. flavus*, lesser corn stalk borer (Mack *et al.*, 1987), and spider mites. Blankenship *et al.* (1993) developed and tested an expert system and prediction model based on rainfall and soil temperature to help manage preharvest aflatoxin contamination.

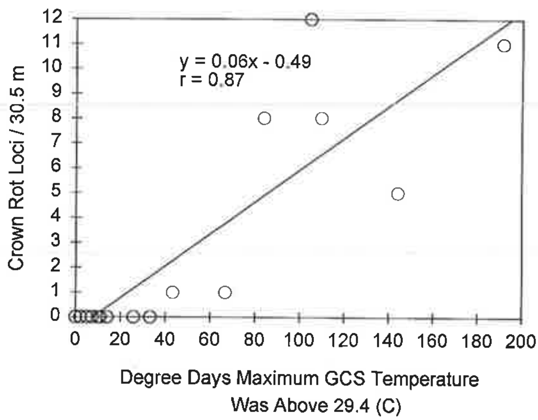

Fig. 7. Typical relationship of maximum of geocarposphere temperature to impact of high temperature pests.

Since effective leaf spot control is essential, these ES provide decisions for applying fungicides for optimum leaf spot control. Generally, leaf spot control begins about 30 to 40 days after planting and subsequent fungicide application sprays should occur at 10- to 14-day intervals (14 to 21 days for Southern Runner), depending on environmental conditions. Adverse weather conditions conducive to this disease exist if (a) during the past 10 days there has been at least 10 hours of leaf wetness each day for 2 consecutive days accompanied by air temperatures above 21 C, (b) leaf spot has been observed on leaf tissue, (c) rain or irrigation is forecast within the next 5 days. Ten hours or more of leaf wetness each day is considered to occur when there has been at least 0.3 cm of rainfall and/or irrigation or there has been a heavy dew that leaves the peanut leaves wet beyond mid morning. The ES recommend applications of fungicide for optimum leaf spot control until 2 weeks prior to harvest. Leaf spot advisories developed by Davis *et al.* (1993), Cu and Phipps (1993), and Nutter and Culbreath (1991) that reduce the amount of fungicides are being considered as options to the standard 10- to 14-day schedule.

Current ES are designed for eight runner-type peanut cultivars (Florunner, GK 7, Sunrunner, Georgia Runner, Southern Runner, OKRun, Marc I, and AgraTech 127), four spanish-type cultivars (Starr, Pronto, Spanco, and Tamspan), and 11 virginia-type cultivars (Florigiant, GK 3, NC 2, NC 4,

NC 6, NC 7, NC 8C, NC 9, NC-V11, VA-81B, and Agra Tech VC-1). ES use the same basic strategy for all cultivars but shifts the management strategies according to differences in phenology. These ES provide information that enable the users to select the optimum cultivar for this management strategy.

Soil classification and grouping is a primary input to these ES. Peanuts are produced on a wide range of soils. Soil scientists Jerry Pilkinton (Soil Conservation Service) and Charles Elkins (ARS, retired) have grouped soils in Georgia, Florida, and Alabama into four categories according to physical properties and other characteristics relative to peanut production. Table 5 summarizes the soil properties and tillage characteristics for each of these four soil categories relative to peanut production.

Category I soils are sandy throughout the surface and subsurface layers and include soils such as Americus (sandy, siliceous, thermic Rhodic Kandiudults), Bonifay (loamy, siliceous, thermic Grossarenic Plinthic Paleudults), Lakeland (thermic, coated typic Quartzipsamments), Lucy (loamy, siliceous, thermic Arenic Kandiudults), and Troup (loamy, siliceous, thermic Grossarenic Kandiudults). Category I subsoil is medium-textured, friable sandy loam or sandy loam clay which begins at a depth between 50 and 200 cm or greater. Category I soils are generally well drained to excessively drained and subject to leaching nutrients below the root zone. Because of their low water-holding capacity, category I soils are not suitable for nonirrigated peanut production, but are well-suited for irrigation. They are easily tilled, but susceptible to compaction by traffic and water. Peanut injury from preplant incorporated (PPI) herbicides is a high risk in these sandy soils especially if cool, wet weather prevails during the seedling growth period followed by drought stress.

Category II soils typically consist of a loamy sand or sandy loam plow layer 12 to 20 cm deep with medium textured friable sandy loam or sandy clay loam subsoils. Norfolk (fine-loamy, siliceous, thermic Typic Kandiudults),

Table 5. Characteristics of the four soil categories used by the expert systems for peanut production management.

Category	Surface layer[a]	Subsoil	Drainage[b]	Water-holding capacity
I	Sand to sandy loam	Sandy loam to sandy clay loam	Excessively drained to well drained	Low
II	Loamy sand to sandy loam	Sandy loam to sandy clay loam	Well drained to moderately well drained	Low to medium
III	Loamy sand to sandy loam	Friable clayey	Well drained to moderately well drained	Medium to high
IV	Loamy sand to sandy loam	Firm clayey	Well drained to poorly drained	High

[a]For moderate or less eroded conditions.

[b]Poorly drained soils are not recommended.

Orangeburg (fine-loamy, siliceous, thermic Typic Kandiudults), and Tifton (fine-loamy, siliceous, thermic Plinthic Kandiudults) soils are typical of category II soils. They are similar to category I soils in that they are easy to till. However, category II soils are not as susceptible to compaction, but tend to have compaction layers nearer the soil surface than category I soils. Their medium textured subsoils are beneficial because they increase the water-holding capacity and prevent pesticide and nutrient leaching. Category II soils are not as prone to PPI herbicide crop injury. However, they are more susceptible to crusting and clodding than those in category I.

Category III soils typically have sandy loam or loamy sand plow layer 12 to 20 cm deep over a friable clayey subsoil. Two examples of category III soils are Faceville (clayey, kaolinitic, thermic Typic Kandiudult) and Greenville (clayey, kaolinitic, thermic Rhodic Kandiudult). These soils are moderately easy to till and are moderately porous. Such soils hold nutrients, chemicals, and water much better than category I or II soils. They are less likely to cause herbicide injury to plant roots. However, category III soils are susceptible to cloding and crusting if not tilled at the optimum moisture content. Tillage management is very difficult in areas of severe erosion. Subsoiling and deep turning may mix the clay subsoil with the topsoil thereby promoting hard soil layers. Because of their higher clay content, peanut harvest should be performed when soil moisture is optimum (not excessively wet or dry) to minimize harvest losses.

Category IV soils are relatively low porosity soils with typically dense or firm clayey subsoils. They are generally classified as highly erodible soils because of excessive runoff. These soils are not recommended for peanut production. If peanuts are planted on these soils, intense land preparation management is required. Carnegie (clayey, kaolinitic, thermic Plinthic Kandiudult), and Esto (clayey, kaolinitic, thermic Typic Kandiudult) are typical category IV soils. Tillage or traffic, including grazing, while these soils are wet increases compaction and produces very hard soil layers when dried. Cloding is a serious problem when tillage occurs under excessively dry conditions. Efficient irrigation on category IV soils is difficult because of their low porosity and excessive runoff. Harvest losses and foreign material can be exceptionally high if peanut digging occurs under dry or wet soil conditions.

SPECIFIC INFORMATION FOR PEANUT PLAN (PNTPLAN)

Knowledge Base

PNTPLAN is a whole farm planning ES designed to optimize peanut based rotation decisions. PNTPLAN generates a farm plan using multi-period linear programming (MPLP) by incorporating specific farm production, financial, crop rotation, and yield data.

The farm owner or manager must define the objectives before a plan can be developed (Kay, 1986). PNTPLAN allows analysis of alternative goals such as various crop enterprise combinations, cost minimization, and profit maximization.

As for any optimization problem, correct estimation of the physical and financial resource constraints is vital to determining the optimum whole-farm plan. Traditional whole farm planning relies on estimating technical coefficients (the amount of a resource input required for production) on land, labor, capital, management, and other resource inputs to determine the enterprise combinations and maximum production levels. Correct estimation of the technical coefficients is often a difficult task. They are programmed into PNTPLAN based on research data and the experiences of farmers, researchers, and extension personnel. PNTPLAN relies on the farmer's practical experience and knowledge to place maximum and/or minimum acreage constraints to minimize reliance on estimating the technical coefficients. Constraints in PNTPLAN provide the upper and lower limitations on the production of certain crop enterprises. If the farmer is analyzing a new crop enterprise where the technical coefficients and constraints are unknown, PNTPLAN can provide initial values by accessing a knowledge base.

PNTPLAN estimates the yield/ha for each potential enterprise in each individual field each year based on the average crop yield, rotation history, and relationship between crop yield and rotation length and suitability. The net return/ha is estimated based on the expected selling price (including deficiency payments, if applicable), total variable cost/ha from crop enterprise budgets and estimated yield. The estimated net returns/ha are used to determine the optimum crop enterprise combinations, field allocations, and acreage levels to optimize the objective function subject to the constraints. The deterministic nature of linear programming models is such that expected yields, prices, and production costs are seldom documented with precision. Thus, PNTPLAN allows sensitivity analysis to be conducted on most input variables. Varying yield, price, and cost levels will affect the optimum crop enterprise allocations and production levels.

Input Data

Input data for PNTPLAN include extensive production and financial data for a specific farm operation. These data can be divided into five separate categories: farm, field, enterprise, equipment, and whole farm operational data.

The farm data apply to separate farms, either rented and/or owned, which are under the whole farm management operation. Data entered at this level include total and cultivatable hectares, quota, yearly principle, interest, taxes, insurance, rent, land and quota purchases. The base acreage of crops in government subsidy programs or conservation programs is also entered which impose acreage constraints for specific crops (set-aside). These constraints can be entered for the farm in general or for a specific field.

The field data apply to each individual field on each separate farm. This data set defines a field as a tract of land with unique characteristics relating to soil type, crop rotation history, and crop production potential. It also includes field identification, soil type, cultivatable area, whether the field is irrigated or nonirrigated, and crop rotation and yield history for the prior 3 production years. Data on rotation and yield history are often difficult, if not impossible, to obtain for prior crop years. Thus, PNTPLAN will function if data on yield history are not available. Adjustments to cash costs of production that might apply to a particular field can be included on the field in the crop level enterprise budgets. An example would be a field with excessive nematode pressure, whereas other fields do not require a nematicide.

At the crop enterprise level, a list of all potential crops which the farmer would like to examine can be used as inputs for PNTPLAN. Budgets are available in PNTPLAN for many potential options and must be completed for all to be analyzed. Yield expectations must be provided for enterprises not produced in prior years. The expected selling price/unit is entered. PNTPLAN analyzes quota and additional peanuts separately because of the distinct price difference. PNTPLAN estimates the net returns/ha above total variable cost for each potential crop enterprise.

A list of the farm equipment inventory is entered with annual principle and interest payments, annual taxes, insurance, and allowable depreciation. This list includes all farm tractors, trucks, implements, combines, irrigation systems, generators, pipe, pumping units, grain bins, shelters, office space, accessories, and similar fixed assets. The percentage of time each individual piece of equipment is used in each crop enterprise is entered, and PNTPLAN estimates the fixed costs.

Whole farm planning is a short- or intermediate-run planning procedure. Therefore, expenses such as property taxes, depreciation, insurance, and opportunity cost on investments are considered fixed and are not subject to change with various crop enterprise combinations or production levels (Kay, 1986). Fixed costs are crucial components of a total farm budget, and the equipment data must be complete. However, if the equipment list is not complete, PNTPLAN will run each enterprise using the returns above total variable cost/ha.

Data which apply to the whole farm operation (not individual farms) are entered at this level. These include principle and interest payments on debts which have accrued through prior years. Long and intermediate-term debt repayments should not include repayment on current production loans, equipment payments, or payments on land or quota purchases. Other payments are unrelated to farming activities but are dependent upon the farm's income (e.g., family living expenses). Other inputs include income from a livestock enterprise, hunting leases, disaster payments, rent, and other miscellaneous income. Outside income is not related to the farming operation (e.g., spouse's salary, dividends from stocks, and interest from savings accounts).

Outputs

PNTPLAN recommends crop enterprise assignments on a field-by-field and farm-by-farm basis utilizing the multi-period linear programming (MPLP) solution. The knowledge base is referenced by PNTPLAN to interpret the results to ensure that recommendations are technically feasible and in compliance with government regulations.

Analysis of rotation patterns cannot be limited to a static (1-year) analysis because of the effects of such changes on future years. PNTPLAN prompts the farmer to choose the number of years to be analyzed (between one and four) and generates a whole-farm plan for the chosen period(s). Reid *et al.* (1980) suggested that MPLP models have two distinct interpretations. The first period can be considered the optimal course of action for the current period given current expectations. Second, a dynamic growth equilibrium over the planning period is provided. Traditional whole farm planning generally excludes enterprises with negative net returns. PNTPLAN does not exclude enterprises with negative net returns because it incorporates the effects of crop rotation sequences into a multi-year analysis. For example, if corn is a potential enterprise and has a negative net return/ha, the 1-year analysis without constraints would exclude corn from the recommendations. However, with a multi-year analysis, the planting of corn might be recommended in a particular field even with negative net returns. If the additional increase in yield and net return/ha of the following crop can be attributed to the inclusion of corn in the rotation sequence and the sum of the net returns over the 2-year period is positive, the changes in the rotation sequence could be recommended.

Current Status

Development of PNTPLAN was initiated in 1990. Since then, 80 farmers in the Southeast have cooperated in developing and validating PNTPLAN. A diverse data base was gathered in the 1991, 1992, and 1993 crop years from farmers in the Southeast for initial evaluation of PNTPLAN. An initial version of PNTPLAN has been programmed. Limited evaluations by cooperators have been initiated. Based on these evaluations, modifications and further improvements will be incorporated into PNTPLAN and the ES will then be validated and released.

SPECIFIC INFORMATION FOR PEANUT TILLAGE (TILNUT)

Knowledge Base

The objective of TILNUT is to provide an optimum schedule of specific tillage and land preparation operations for either irrigated or nonirrigated peanut production. TILNUT will provide decision support for the period from immediately after harvesting the preceding crop until peanuts emerge.

TILNUT helps make decisions for peanuts regarding land preparation for the forthcoming peanut crop. Land preparation usually begins soon after harvest of the rotational crop immediately preceding peanuts. It is based on the principal of providing a residue-free seedbed with sufficient moisture to establish strong and vigorous peanut seedlings (Henning *et al.*, 1982; Baldwin and Bader, 1992). Some of the factors affecting the type and timing of land preparation for peanut production are the preceding crop, soil type, field slope, pest history, fertility, time of year, and whether or not the field will be irrigated. The goal is to achieve optimum economic returns when constrained by various regulatory requirements related to soil erosion. The optimum decision requires knowledge from many areas of scientific expertise such as soil science, agronomy, entomology, pathology, and engineering. In addition, the practical knowledge of the expert farmer or consultant as to how a crop performs in a specific field are primary inputs.

Input Data

Data required for TILNUT include many of the same data required for other production management systems—e.g., field name, slope, soil type (common name), rotation, pest history, and the availability of irrigation (Table 1). Like PNTPLAN, the farmer needs to provide a list of available equipment for land preparation and tillage including (a) the number, type and power of tractors available; (b) the primary tillage equipment; and (c) secondary tillage equipment. Personnel and financial data are also necessary. These data provide a basis for optimum recommendations for a given field.

TILNUT requires rotation data including the preceding crop and land preparation for the peanut crop. Some typical questions are:

(a) Has the crop immediately preceding the peanut crop been harvested?
(b) Has the crop residue been removed or buried?
(c) Have soil samples been taken to determine nutrient and nematode control requirements?
(d) What weeds are present and at what stage of growth?
(e) What is the soil condition relative to moisture and tillage?

The ES stores the data in a permanent file by the dates each event occurred, providing a detailed log for future reference and use by other management systems.

Outputs

Beginning just prior to harvest of the crop preceding peanuts, the farmer may begin requesting advice (outputs) from TILNUT. For example, to determine the optimum land preparation schedule for the 1995 peanut crop following corn, the grower could first begin using TILNUT in the fall of 1994 just prior to corn harvest. The ES recommends a detailed schedule for land preparation tasks. TILNUT considers the proper management of pests, corn litter, soil fertility, soil erosion, and soil water conditions from the current date through seedbed preparation and spring planting. During subsequent sessions, the user will confirm prior activities thus providing a log for future reference and recommendations. A new recommended schedule for land preparation will then be produced. If requested, TILNUT will provide the reasons for the recommendations.

Current Status

The written knowledge base was completed by a team of experts on July 30, 1992. In May 1993, an initial version of the ES was developed for the category III nonirrigated soils and is being reviewed by experts. The current focus is validation of the decisions for category III soils and obtaining additional information for conservation tillage.

SPECIFIC INFORMATION FOR EXPERT PEANUT IRRIGATION (EXNUT)

Knowledge Base

The objective of EXNUT is to improve economic returns for irrigated peanut production and to reduce the risk associated with aflatoxin, foreign material, immaturity, off-flavor, chemical residues, and environmental impact. EXNUT was designed to accomplish this objective by scheduling irrigation to minimize the adverse conditions. It programs irrigation for development of a deep root system, reduced vine growth, maximum fruit set, rapid maturation, reduced harvesting losses, and a reduction in the use of irrigation and chemicals.

EXNUT helps the user make irrigation decisions through a series of basic questions concerning weather, soil type, soil water, irrigation capacity, soil temperature, date, time since planting, and crop condition. The irrigation strategy is based upon field research data and knowledge obtained during crop years 1980-1984 and validated during crop years 1985-1993 (Davidson, 1988, 1989, 1990; Davidson and Lamb, 1991; Davidson *et al.*, 1992, 1993, 1994). Generally, this strategy schedules irrigation that maintains an optimum soil temperature range in the pod zone (geocarposphere) (Davidson *et al.*, 1991). This helps control pests, achieve rapid emergence, promote good tap and lateral root growth (Ketring and Reid, 1993), prevent excessive vine growth, provide optimum conditions for fruit addition and maturation, and provides optimum plant and soil conditions at harvest (Figs. 8-10) unless hampered by excessive rainfall.

EXNUT considers two soil type groups—(a) sandy (category I), with no significant amounts of clay in the top 76.2 cm, (Lakeland to Americus) and (b) medium-heavy (categories II, III and IV, Redbay to Tifton to Greenville). EXNUT usually recommends more water per application and more frequent irrigation on sandy than on medium-heavy soils.

EXNUT considers only two classes of irrigation systems, adequate and inadequate. Adequate systems are capable of delivering 25.4 cm of water in 40 days for sandy soils (category I) and 20.3 cm of water in 40 days for medium-heavy soils (categories II, III, and IV) during the primary fruiting period. The adequate system also must be able to deliver at least 5.1 cm of water within a 7-day period. Following this system contributes to the initiation of maximum fruiting by reducing soil temperatures to the optimum range (21.1-30.6 C).

Systems with inadequate capacity cannot deliver this amount of water and need supplemental rainfall to help reduce soil temperature essential for optimum flowering and fruiting. Should irrigation capacity status change during the season (larger system installed, water supply diminishes, system failure, etc.), the field name can be changed and data re-entered to run EXNUT using the new status. EXNUT uses a much more conservative (less

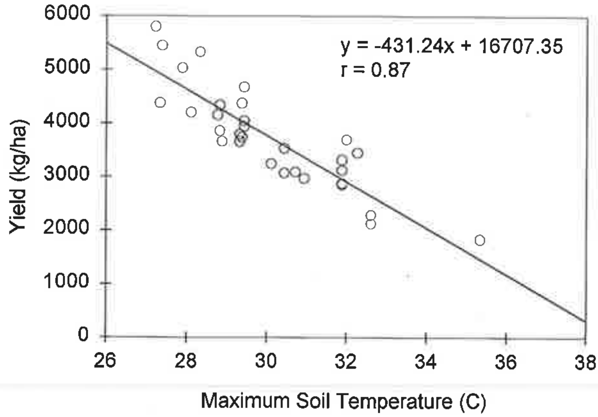

Fig. 8. Typical relationship of maximum geocarposphere temperature during primary fruiting period to final yield.

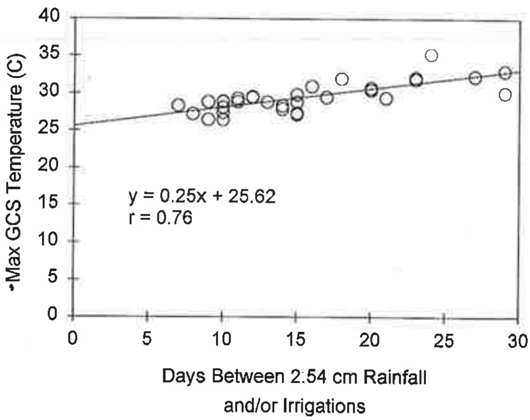

Fig. 9. Typical relationship between maximum geocarposphere temperature and frequency of rainfall and/or irrigation.

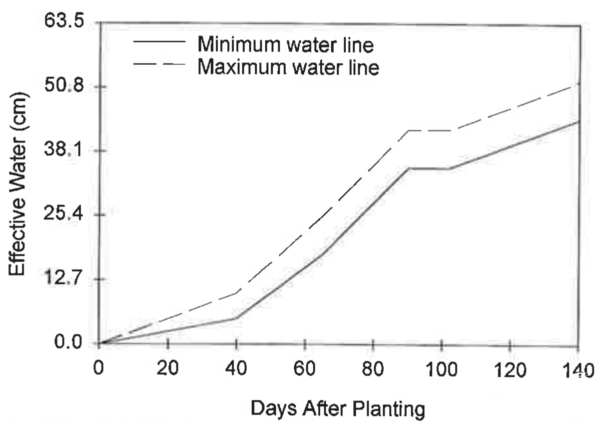

Fig. 10. Typical patterns of effective water to maximize economic returns and quality while reducing use of natural resources and pesticides.

water and less frequently applied) irrigation strategy for the fields with inadequate than for those with adequate irrigation systems.

EXNUT considers two attainable yield potentials: greater than 5600 kg/ha and less than 5600 kg/ha. High attainable yield potential fields are characterized by being level to near level (0-2% slope) with well-drained soils, medium fertility, low soil and plant pest pressure, and recommended crop rotation. It must have rainfall and adequate irrigation capacity. EXNUT also uses a more liberal irrigation scheduling for the high attainable yield potential.

EXNUT includes eight phases of scheduling irrigation (*not* to be confused with the time periods previously defined in this chapter) as follows: (a) preplant, (b) planting to 10 days after planting (DAP), (c) 11 to 25 DAP, (d) 26 DAP to fruit initiation, (e) FI to 20 days after FI, (f) 21 days after FI to 40 to 50 days after FI, (g) drying out-period (usually 8 to 14 days), and (h) from end of drying out period to harvest.

In the preplant stage, EXNUT schedules irrigation prior to planting only when needed to minimize wind erosion, activate herbicides, minimize herbicide injury, and provide good soil moisture for planting. Irrigation amounts/application usually range between 0.8-1.3 cm to activate preplant herbicides except when trying to obtain a good moisture profile for planting. To obtain a good soil moisture profile, an irrigation system must provide sufficient effective water to achieve near field capacity. EXNUT schedules irrigation in the second and third stages only to minimize wind erosion, obtain emergence, activate herbicides, and minimize the effects of a hardpan. Amounts required are similar to those in the preplant stage. Minimizing the hardpan requires ample water to wet the soil profile 15 cm below the hardpan. EXNUT generally withholds irrigation from 26 DAP to FI to prevent waterlogging and thereby promoting rapid and deep root growth while restraining vine growth. Exceptions include irrigation to minimize wind erosion, alleviating herbicide injury, or reducing high temperature pests such as crownrot seedling disease and the lesser cornstalk borer. Such irrigation needs would only require 1.3 to 1.9 cm of effective water. During stages 4 to 8, the irrigation strategy for the adequate versus inadequate irrigation systems is different. On fields with adequate irrigation systems, EXNUT schedules irrigation events of 2.5 to 3.8 cm per application just prior to FI. From FI to 40 to 50 days after FI, EXNUT schedules irrigation (2.5 to 7.6 cm per application) on a frequent and regular basis so the plant will partition more of its energy to fruiting rather than to vegetative growth (root and canopy). For inadequate systems, EXNUT will generally delay irrigation until FI occurs on the assumption that rainfall may occur thereby initiating fruiting prior to recommending irrigation during stage 4. During stages 5 and 6 for the inadequate systems, EXNUT will generally recommend 3.8 cm/application as needed to reduce the soil temperature in the fruiting zone to acceptable levels (21.1-29.4 C). After stages 5 and 6, EXNUT schedules a drying out period (8-14 days) for adequate and inadequate systems to minimize pest pressure and to encourage rapid maturation. After the drying out period, EXNUT schedules irrigation (generally 3.8 cm/application) to provide soil temperatures that promote rapid maturation, low pest pressure (including aflatoxin), and low risk of excessive digging losses. During this last stage, EXNUT uses a conservative irrigation strategy based on the assumption that there will be some moisture by rainfall. Throughout most of the eight stages, EXNUT considers the probability of rainfall. The risk of excessive water is high during stages 2-5, 7, and 8. Thus, an insufficient or excessive amount of water will increase the risk of reducing yield, quality, and economic returns. EXNUT uses minimum and excessive water patterns indicated by Fig. 10 to reduce excessive irrigation or severe drought.

When scheduling irrigation to prevent drought stress, EXNUT recommends applying an amount between 1.9 cm and 5.1 cm of total water. However, multiple applications may be necessary during high temperature and low humidity conditions and to prevent runoff.

EXNUT assumes that liming, fertilization, irrigation system maintenance and calibration, land preparation, and other cultural practices have been accomplished in accordance with the latest recommendations by the state Cooperative Extension Service's Peanut Production Guide (e.g., Henning *et al.*, 1979; Johnson, 1987). EXNUT also assumes that timing and selecting herbicides and pesticides other than leaf spot fungicides will be in accordance with EXNUT alerts, and as specified by the Integrated Pest Management Program of the Cooperative Extension Service (e.g., Brown, 1991).

Input Data

EXNUT inputs include (a) field name, (b) date, (c) planting date, (d) soil type, (e) yield potential, (f) crop rotation, (g) variety, (h) irrigation capacity, (i) fruit initiation date, (j) canopy coverage, (k) effective water record, (l) maximum and minimum GCS temperature, (m) whether or not there is visual plant stress, (n) probability of rain in next 2 days, (o) whether or not leaf spot is present, (p) date of last fungicide application, and (q) whether or not there has been 2 consecutive days having more than 10 hours of leaf wetness during the last 10 days.

Outputs

EXNUT asks questions until it has considered all rules relevant to the possible decisions. Each decision listed will have a probability value. EXNUT uses a 0-10 confidence system with the higher number indicating higher confidence in the decision. The decisions are displayed and arranged in order by final value with the most likely first, next most likely second, etc. EXNUT outputs include (a) whether or not to irrigate, (b) when to run the ES again, (c) the amount of irrigation needed, (d) whether or not to apply an approved fungicide for leaf spot control, (e) when there is a need to scout for high or low temperature pests, (f) reasons for decision (optional), and (g) explanation of terms and strategy (optional).

Status

Since 1985, EXNUT has been evaluated in Georgia and, since 1989, in the other nine growing areas (Alabama; Florida; east and west Oklahoma; North Carolina; central, east, and west Texas; and Virginia). The results of these evaluations have been published in the University of Georgia Research-Extension Reports (Davidson, 1988, 1989, 1990; Davidson and Lamb, 1991; Davidson *et al.*, 1992, 1993, 1994; Davidson and Baldwin, 1994) and a paper written for ASAE (Davidson *et al.*, 1990). Ratings during crop year 1993 by county agents and the Georgia Cooperative Extension Service was good (Fig. 11). Similar results were obtained in Alabama, Florida, North Carolina, and Virginia. Early frosts and/or inclement weather prior to harvest has confounded evaluations in the Southwest. EXNUT is continually being validated, revised and updated to include the latest technology and improve its user-friendliness.

On-farm comparisons with expert farmers in Georgia were conducted from 1987 to 1990 on 32 farms (Davidson *et al.*, 1990). Expert farmers used EXNUT to manage at least one field while using their own management strategy on a nearby or adjacent field with similar soil type, crop rotation history, and yield potential. The benefits of EXNUT were probably greater than the data indicate because the expert farmers, often, changed their own management decisions to agree more closely with those made by EXNUT. Over the 4-year period, EXNUT resulted in a higher average yield and grade. This increase occurred in spite of the farmer's extensive knowledge of the field history, the knowledge of EXNUT decisions, and reason for these decisions.

The 4-year average yield increases associated with running EXNUT in commercial peanut fields was 207 to 797 kg/ha compared to expert farmers and average irrigated farms, respectively (Table 6). EXNUT increased grade 1 to 5% (SMK + SS) when compared to the expert farmers. Estimated increases in yield of 336 kg/ha and 2% in grade were associated with EXNUT. These estimates are for comparison purposes only but are based on actual data gathered during crop years 1987 through 1991.

Generally, EXNUT controlled leaf spot without loss of yield or quality. Leaf spot control advisories and options, such as AU-PNUTS (Davis *et al.*,

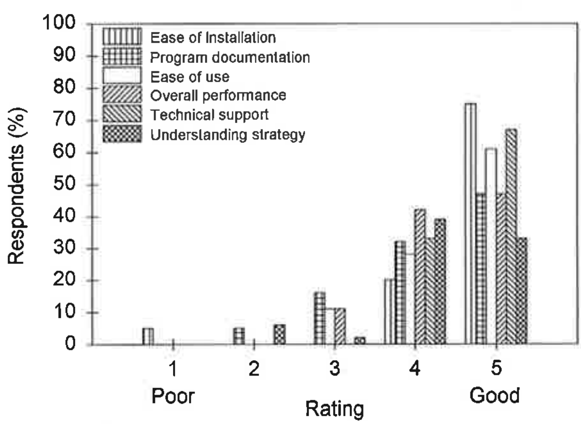

Fig. 11. EXNUT ratings during crop year 1993 by county extension agents and the Cooperative Extension Service.

Table 6. Mean yields from nonirrigated and irrigated peanut fields taken from field surveys and from fields experimentally managed by the EXNUT irrigation strategy.

Crop year	n[a]	Non-irrigated[b] yields	n	Irrigated[b] yields	n	EXNUT[c] yields	n	Expert[d] farmer yields
		kg/ha		kg/ha		kg/ha		kg/ha
1987	23	2809	21	3449	8	3906	8	3852
1988	29	3060	24	3587	11	4347	11	4301
1989	37	3651	26	3598	7	4406	7	4080
1990	28	1608	23	2892	6	4057	6	3654
Avg	29	2782	24	3382	8	4179	8	3972

[a]Number of sample observations.
[b]Data from field surveys.
[c]Data from expert farmers on EXNUT managed fields.
[d]Data from expert farmers' conventionally irrigated fields.

1993), have potential for reducing the number of fungicide applications. EXNUT also provided yield results similar to AU-PNUTS. Thus, use of these options in EXNUT would result in lower per unit costs of production and a reduction of fungicides in the environment as compared to the standard 10- to 14-day schedule. Aflatoxin was not detected (<1 ppb) in peanuts (edible grades) grown in fields managed by EXNUT and foreign material was below average (<4%) in these peanuts. Peanut seed from fields managed by EXNUT had high germination percentages (>80%). The maturity profile as determined by the hull scrape (Williams and Drexler, 1981) was optimum. Lamb *et al.* (1993) estimated cost of incorporating EXNUT into an actual farm situation is $5.41/ha and concluded that EXNUT would increase the net returns associated with irrigated peanut production.

SPECIFIC INFORMATION FOR DRYLAND PEANUT PRODUCTION (DRYNUT)

Knowledge Base

The objective of DRYNUT is to minimize the environmental and economic risks while maximizing the economic return and quality for nonirrigated peanut production. Compared to irrigated peanut production, not irrigating is very risky relative to yield, quality, and economic returns because of the uncertainty of weather and pest activity. Extended periods of drought about the time of planting can produce a dry, cloddy seed bed, poor preplant pesticide performance, and poor emergence. Extended periods of drought after planting are detrimental to yield and quality. Drought may affect emergence, pesticide application and activity, plant health, root penetration of the plowpan, fruit addition, calcium uptake, seed maturity, aflatoxin contamination, harvest losses, off-flavor, chemical residues, and subsequent seed germination. Peanut production costs generally exceed $1235.50/ha and a crop failure because of drought results in a significant economic loss. Selection and scheduling of production practices are complex and require the application of the best knowledge available.

Because of the favorable response of peanut to irrigation, DRYNUT also includes an option for determining the feasibility of irrigation. If other ES such as PNTPLAN, TILNUT, and MNUT are used on a specific field, much of the data can be retrieved from the respective data files. DRYNUT has seven program modules that cover (a) the irrigation feasibility option, (b) the preplant time period, (c) planting to emergence, (d) emergence to fruit initiation, (e) the primary fruiting period, (f) the maturation period, and (g) the period during harvest. Within modules 2 to 7, there will be program loops for managing cultural practices, fertility, diseases, nematodes, insects, and weeds.

Portions of the DRYNUT knowledge base that have not been covered in the TILNUT or EXNUT sections are briefly outlined below. Consideration of the feasibility of irrigation (whether or not to invest in irrigation equipment) is a complex issue which varies from farmer to farmer and field to field, particularly under varying soil type characteristics. Not all fields are suited for irrigation. DRYNUT considerations are both technical and financial.

The technical considerations include soil type, field size, shape and slope, availability of water, the need for portability, and grower attitudes toward peanut quality. If the field can be irrigated, the best type of irrigation system is determined for each field. Because of differences in equipment cost, financial considerations of the various irrigation systems are analyzed. If financial constraints do not affect the type of irrigation, the analysis made on the system needed is determined by soil type, field size, shape and slope, and the need for portability of the system. Calculations are based on adequate capacity of the irrigation system. Systems with inadequate capacity are not generally profitable, especially on category I soils.

Assumptions must be made by the farmer for all crops which are to be irrigated with the proposed system. These include expected yield, selling price, and cash cost of production (for nonirrigated and irrigated for comparison purposes). DRYNUT provides limited guidance in these areas based on previous research and farm experience. Agricultural policy is considered because the assumptions extend over the useful life of the irrigation system. Budgeting considerations include financial arrangements which are used for determining fixed costs and the farm's current and future financial status.

Equations have been programmed into DRYNUT for estimating the fixed cost/year of irrigation equipment. Data for these equations include the purchase cost, expected years of useful life, quantity, and expected salvage value for the irrigation system, power unit, water source, pump/gear head, land development, pipes and risers, generator, and freight/installation. DRYNUT calculates the total fixed costs/year and the fixed cost/ha/year. Sensitivity analysis of cost is allowed so that varying purchase cost, life, etc. can be analyzed. Analysis of used equipment is also allowable.

The farm's financial status includes analysis of management practices such as cash flow analysis, debt/asset ratio, return on investment, credit considerations, leasing, etc. Much of this information is contained in PNTPLAN.

Considerations of cultural practices are dependent on soil type for dryland peanut production because soil type usually dictates which tillage methods and tools are best suited to achieve an optimum seedbed. This information has been outlined in the General and TILNUT knowledge base sections.

Adequate moisture is essential for seed germination and obtaining an optimum stand. Therefore, all tillage should be completed and soil moisture replenished just prior to planting. Planting in dry soil with expectation for rain is extremely risky if, when rain occurs, it is only enough to start the germination process. Plant stands can be severely reduced by such conditions. A stable, or settled, firm seedbed with adequate moisture from the surface to 30.5 cm deep is desirable. A soil temperature optimum for planting as recommended by the State Extension Services is beneficial in obtaining a good stand. A forecast for continued favorable weather during the next 3 to 5 days, high quality seed, and recommended management practices will produce the desired plant population/ha in most years. DRYNUT will make recommendations for selecting cultivars and provide information on seed count, seed spacing, amount of seed required, row spacing, planting dates, seed depth, replanting, and optimum harvest dates. Fertility strategy is based on soil tests, crop rotation, soil type, time of year, and cultivars. DRYNUT will make recommendations for applying lime, fertilizer, gypsum, and seed inoculant.

Soil may be sampled and tested following breaking. Alternatively, the soil may be sampled in the winter or early spring prior to breaking. However, sampling after breaking may still be required to adequately assess calcium level in the pegging zone.

DRYNUT weed control strategy is based upon a matrix of information on weeds, herbicides, herbicide effectiveness, cost, environmental conditions, cultivars, and time frames. Computer programs or data bases such as HERB, developed for herbicide selection in soybean (Wilkerson *et al.*, 1991) would be useful for weed management in peanut. The program HERB has been modified for peanut and is under field verification (B. J. Brecke, pers. commun., 1994). DRYNUT insect control strategy is based upon scouting reports, environmental conditions, threshold values, time frames, and insecticide information. DRYNUT disease and nematode control strategy is based upon scouting reports, field history, soil assays for nematodes, crop rotation, variety, soil type, soil fertility, chemical data, and time frames. Leaf spot management was described in the General section.

Input Data

Typical DRYNUT inputs include (a) field name, (b) date, (c) soil type, (d) yield potential, (e) crop rotation, (f) pest severity in past peanut crops, (g) planting and emergence date if already occurred, (h) cultivar planted if planted, (i) canopy coverage, (j) effective water record, (k) maximum and minimum GCS temperature, (l) degree of plant stress, (m) probability of rain in next 2 days, (n) scouting information, (o) chemical usage since last DRYNUT run, and (p) fruit initiation date (FI).

Outputs

DRYNUT will ask only questions relevant to the possible solution. It will then display the selection of optimum cultural, fertility, weed, insect, disease, and nematode control practices for the field and situation in question. Typical outputs for DRYNUT include recommendations (if required) for (a) cultural practices, (b) weed control, (c) disease control, (d) insect and nematode control, (e) fertility practices, and (f) when to scout the field and run DRYNUT again.

Status

The written knowledge base for Alabama, Florida, and Georgia versions were completed during 1993. After review and approval by the State Extension specialists in each state, the flow charts and rules will be developed for programming. A similar knowledge base will be developed and programmed to include the latest research findings and expert knowledge. The goal is to have an Extension and a Research version ready for validation in each of the above-mentioned three peanut growing states in the Southeast by CY 1995 and in the other growing areas by 1996.

SPECIFIC INFORMATION FOR MARKETING PEANUTS (MNUT)

Knowledge Base

MNUT is a management ES designed to reduce the risk of marketing peanuts associated with variability in peanut yield, quality, and price. MNUT accomplishes the objective of assisting with marketing decisions by providing timely and objective predictions of peanut yield, quality, and price to assist in marketing decisions. MNUT is divided into two separate, yet linked, modules—the yield and quality prediction module and the price prediction module. The equations in MNUT are estimated for the following plant growth stages: (a) preplant, (b) planting to FI, (c) FI to 20 days after FI, (d) 21-41 days after FI, (e) 42-62 days after FI, and (f) 63 days after FI to harvest.

Input Data

Multiple variable regression is used to estimate the equations in the yield and quality module of MNUT and references the optimal water, soil temperature, and other inputs for the specific plant growth stage. Optimal water, soil temperatures, and other inputs are determined statistically from the data bases, where data exist; and are included in the knowledge base from the experiences of the experts (listed in acknowledgments) where data do not exist.

The data required to run the yield and quality module in MNUT are gathered from a geographically diverse cross-section of the peanut belt in each region (Table 1). The fields are selected based on soil type, irrigation percentages, management practices, and similar variables (Table 1) which are representative of the region. Cooperating field scouts obtain preplant and cultural practice data from the farmers. At planting, field scouts monitor fields weekly until harvest to gather rainfall, irrigation, and maximum-minimum soil temperature data and to scout fields for pests. Scouts make no recommendations to farmers. These data are delivered to the USDA-National Peanut Research Laboratory (NPRL). Predictions are initiated the last week of July and updated weekly until harvest. At the time of marketing, all loads from each field are graded and marketed through commercial facilities to provide field yield and grade data. Samples are collected and evaluated to determine shelling outturns, germination, and aflatoxin level.

Outputs

The model to predict peanut yield in an individual field is specified as:

$$Y,Q'_s = f(Y_p, R_o, S_t, S_p, W_s\text{-}RW_s, T_s\text{-}RT_s) \qquad \text{(Eq. 2)}$$

where:

- Y,Q'_s = the predicted yield and quality during a specific plant growth stage(s),
- Y_p = the field yield potential (kg/ha),
- R_o = crop rotation (number of years between peanuts),
- S_t = the predominant field soil type,
- S_p = the percent of slope in the field,
- W_s = the water received during the plant growth stage as recorded by field scouts,
- RW_s = the optimal water amount during the plant growth stage,
- T_s = the maximum geocarposphere temperature during the plant growth stage as recorded by field scouts, and
- RT_s = the optimal maximum geocarposphere temperature during the plant growth stage.

Quality is predicted in terms of seed size distribution, germination, and aflatoxin contamination. Aflatoxin contamination levels are modeled using expressions similar to those used by Blankenship *et al.* (1993).

The data required to run the price prediction module in MNUT is the output (predictions) from the yield and quality predictions. These modules are linked so that the output from the yield and quality predictions are entered into the price prediction equations along with the other input variables, and then calculated. The quality prediction equations are specified similarly except Y_p is omitted.

The predicted yield and quality for individual fields are averaged to provide county, state, region and national peanut yield and quality estimates. The quality predictions "adjust" the yield predictions to reflect the removal of peanuts from edible channels due to sub-standard quality. Hence, quality adjusted supply positions for farmers stock and shelled stock peanuts by outturn class can be estimated.

An assumption of the price prediction models is that the supply of farmers stock peanuts is predetermined (by the yield and quality predictions) and the seasonal average prices are discovered by market trading. The direction is from quantity (quality adjusted quantity) to price (Judge *et al.*, 1980; Tomek and Robinson, 1981). Price flexibility coefficients can be estimated that imply price is a function of the quantity produced and processed. The price prediction equation for farmers stock peanuts is estimated using an ordinary least squares regression. The model is specified as:

$$P = f(S^{-}_{s}, B_i, O_p, U_p, D_p) \qquad \text{(Eq. 3)}$$

where:

- P = seasonal average price of farmers stock,
- S^{-}_{s} = predicted current year supply of farmers stock peanuts available for edible channels.
- B_i = beginning peanut stocks and imports,
- O_p = predicted peanut production in other U.S. peanut production areas,
- U_p = U. S. population, and
- D_p = national disposable income.

The price flexibility among the shelled stock outturn classes are estimated by MNUT as a system using seemingly unrelated regression analysis. Estimating the equations as a system should improve efficiency compared to estimating the equations individually even if the equations do not directly interact as long as their error terms are related (Kennedy, 1985; Lamb, 1990). Although peanuts in a particular shelled stock outturn class are destined to a particular consumer product, limited substitutability among classes occurs because of stochastic factors (generally weather). Incorporating substitutability as a random shock among classes due to stochastic factors is appropriate because prices of the outturn should be affected similarly. Thus, limited substitutability among shelled stock peanut prices is analyzed. The model is specified as:

$$P_{ja}=f(Q^{-}_{ja}, B_i, O_p, U_p, D_p) \qquad \text{(Eq. 4)}$$

where:

- P_{ja} = the season average price per pound of shelled stock outturns by class 'j' from a defined production area 'a' (Southeast, Virginia-Carolina, Southwest), and
- Q^{-}_{ja} = the predicted quantity of shelled stock outturns by class 'j' which are quality adjusted to reflect the quantity available by area 'a' for consumption.

All other variables are previously defined.

The price prediction for seed is made for seed price in the next year. A primary objective of the seed price prediction is to provide information to farmers who might wish to retain some of their own peanuts as seed. This can be an attractive alternative, especially in years when limited production has an inflating effect on seed prices for the next year. The model for seed prices is specified as:

$$SP^{t+1}_{a} = f(Q^{t}_{w}, B_{i}, O_{p}, U_{p}, D_{p}) \quad \text{(Eq. 5)}$$

where:

SP^{t+1}_{a} = predicted price for seed peanuts next year, and

Q^{t}_{w}, = predicted quantity (quality adjusted) of the jumbo, medium and number 1 shelled stock outturn classes (splits cannot be used as seed stock).

All other variables are previously defined.

STATUS

Since 1987, MNUT has been evaluated primarily in the Southeast by cooperating industry segments. The number of fields evaluated in the Southeast from 1987 through 1992 were 54, 68, 76, 81, 95 and 102, respectively. Evaluations on a limited basis were initiated in the Virginia-Carolina and Southwest regions in 1989. The predictions of peanut yield, quality and price were initiated the last week of July each year and updated weekly until harvest as additional field data was gathered. The July MNUT prediction of peanut yield in the cooperating fields was within 8.1% of the actual field yield. Predictions (July) of farmers stock grade, aflatoxin in the oil stock, percentage jumbos, and seed germination were within 1.3%, 16.7 parts per billion (ppb), 1.0 and 2.2% of the actual values, respectively.

The predicted field yields are utilized to estimate a weighted average yield for larger geographic yields (county, state, regional, and national). Conversion factors, which relate a particular field's average historical peanut yield to the yield of the larger geographic unit, are used to obtain a predicted peanut yield on a geographic basis. The predicted yields in the Southeast averaged 6.73% of the actual yields. The yield prediction, after adjustments for inferior quality (from the quality predictions) are incorporated, is multiplied by the peanut ha in the Southeast to obtain a prediction of edible peanut supply in the Southeast.

On the average, MNUT predicted the price of farmers stock, seed, jumbos, mediums, number 1's and U.S. splits within 0.007, 0.011, 0.020, 0.026, 0.024 and 0.025 dollars per kg of the actual season average prices for each category, respectively.

SPECIFIC INFORMATION FOR HARVESTING PEANUTS (HARVPRO)

Maintaining plant health and determining the optimum time for harvest are the primary considerations at harvest. Diseases tend to explode near harvest. Disease pressure and environmental conditions must be considered, especially relative to pod rot and limb rot. Soil moisture is a significant factor, because the soil can become so dry and hard that it may be impossible to dig the peanuts on category III and IV soils. Other considerations in making harvesting decisions include weather, available machinery and personnel, and number of acres to be harvested. HARVPRO will use much of the information required by EXNUT, DRYNUT, and MNUT, including FI date, field scout reports, effective water, and soil temperature records. Digging data projections are based on the hull scrape pod maturity profile (Williams and Drexler, 1981).

Computer software has been developed to interpret the hull scrape pod maturity profile. The knowledge base for HARVPRO is being compiled for preparation of the written knowledge base.

SPECIFIC INFORMATION FOR PEANUT CURING MANAGEMENT (PECMAN)

Knowledge Base

The primary objectives of PECMAN is to provide the dryer operator with (a) the optimum control strategy that maintains high peanut quality at the least cost, and (b) a tool to maintain a permanent record of the drying operation on each load of peanuts. After the producer has grown and harvested a quality peanut crop, the moisture content must be reduced to levels suitable for long term storage in warehouses or bins. Extensive research has shown that the conditions of the air used to cure (dry) peanuts affect quality in terms of dry matter decomposition, shrinkage, flavor, fungal contamination, germination, seedling vigor, and milling characteristics (Beasley and Dickens, 1963; Woodward *et al.*, 1970; Woodward and Hutchison, 1972; Blankenship and Pearson, 1976; Slay, 1976; Hung, 1989; Sanders *et al.*, 1989). Improperly curing peanuts can significantly decrease seed and edible quality (Ketring, 1993).

Current recommendations for drying peanuts specify an air flow rate ranging from 10 to 19 m^3/min of peanuts in the bin (Samples, 1984; Cundiff *et al.*, 1991). Drying air should be heated no more than 8 C above ambient temperature and no higher than 35 C. Following these recommendations will generally cure peanuts in a reasonable amount of time while maintaining peanut quality. Computer simulation models have been written and validated to estimate the drying time, energy consumption, and moisture gradient from bottom to top of the peanut bin (when given the initial or current moisture content, temperature and humidity of the ambient air, and thermostat setpoints) (Chinnan and Young, 1978; Troeger and Butler, 1979; Troeger, 1982; Colson and Young, 1990). Troeger (1989) subsequently developed mathematical relationships correlating the accumulated time that the peanuts are exposed to air with relative humidity less than 50% to the minimum percentage of split kernels that can be expected when the peanuts are initially marketed. These relationships were incorporated into the drying simulation model.

Although the models described provide a relatively accurate estimate of the drying time, they have not gained acceptance as tools for managing peanut drying facilities. Using simulation models, Troeger developed a series of regression equations to estimate the drying time, minimum percentage of split kernels, amount of propane gas, and the cost of drying a load of peanuts with various thermostat settings (J. M. Troeger, unpubl. data, 1992). Data required are the expected daily maximum and minimum ambient air temperatures, maximum allowable temperature rise, maximum allowable plenum temperature, and an estimate of the air flow rate and the current moisture content. PECMAN uses these regression equations to optimize the thermostat setting, subject to constraints of the drying facility. If the constraints are too restricting and cannot be met, PECMAN will advise the user of the best strategy to try to meet those constraints.

Input Data

Similar to the structure for the production management system, some data are constant for the entire harvest season that requires entry only at the beginning of the season with updates throughout the curing process. Data describing the physical setup of the drying equipment is necessary for optimum decisions, including (a)the total number, type and location identity of operational dryers at the facility, and (b) the desired cutoff moisture content for edible trade peanuts and seed peanuts. If changes occur during the year, the data can be updated as necessary. For example, the incoming quality of the peanuts may require that the cutoff moisture content be decreased to reduce the range of single kernel moisture content. The daily maximum and minimum ambient air temperature should be provided. If the temperature data are not available, the historical average will be used.

The moisture content of the load of peanuts must be input and updated periodically during drying. After the trailer is initially sampled and connected to the dryer, the operator should designate the location of the trailer and the initial moisture content.

Output

After the input data are provided, PECMAN estimates the curing time for optimum quality and minimum variable drying costs. PECMAN maintains a log of all trailers being cured and displays it on the computer screen. As the trailers are sampled and the moisture content determined, the updated data is entered. New estimates of the completion time are determined and displayed. PECMAN indicates the next time each load should be checked.

Current Status

PECMAN is in the development and validation phase. The user interface is currently being developed and was tested during the 1993 harvest season. Testing was performed at commercial drying facilities in the southeastern U.S. that handle farmers' stock peanuts for the edible and seed market. As the comments are received and revisions made, the ES will be expanded and modified for conditions in the other peanut producing regions of the U.S.

SUMMARY

Technology development and research data have doubled over the past decade and is expected to triple over the next decade. The Cooperative

Extension Service and the peanut industry need new technology transfer methods which can provide expert knowledge that embraces cost effective and environmentally sound decisions to users that will minimize risk. ES are a proven technology transfer tool which can efficiently incorporate scientific research data and the knowledge of experts into deliverable technology transfer packages to assist in management decisions. Through cooperative, multi-disciplinary, multi-agency research efforts, ES are being developed to provide technology transfer tools to manage peanut production, harvesting, marketing and processing.

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Contributor	Affiliation	DRY	EXN	HAR	MNU	PNT	TIL	PEC
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Dr. John Baldwin	UGA, CES	X	X				X	
Mr. Dallas Barnes	Severn Peanut Company				X			
Mr. Tommy Bennett	USDA, ARS	X	X					
Mr. Bill Birdsong	Birdsong Peanut Company	X			X			
Mr. Jimmy Blitch	GACCP	X	X	X	X	X	X	X
Dr. Steven M. Brown	UGA, CES	X						
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Dr. Danny Colvin	UF, CES	X						
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Mr. Stanley Copeland	Farmer		X			X		
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Ms. Kim Cutchins	National Peanut Council	X	X	X	X	X	X	X
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Contributor	Affiliation	DRY	EXN	HAR	MNU	PNT	TIL	PEC
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[1]Abbreviations: DRY = DRYNUT, EXN = EXNUT, HAR = HARVPRO, MNU = MNUT, PNT = PNTPLAN, TIL = TILNUT, PEC = PECMAN, UGA = University of Georgia, CES = Cooperative Extension Service, USDA = United States Department of Agriculture, ARS = Agricultural Research Service, GSDC = Georgia Seed Development Commission, GACCP = Georgia Agricultural Commodity Commission for Peanuts, AU = Auburn University, DAERS = Department of Agricultural Economics and Rural Sociology, SCS = Soil Conservation Service, OSU = Oklahoma State University, NCSU = North Carolina State University, UF = University of Florida, and FSIS = Federal State Inspection Service. Mention of a trademark or proprietary product does not constitute a guarantee or warranty of the product by the USDA and does not imply its approval to the exclusion of other products that also may be available.

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