Validation of EXNUT for Scheduling Peanut Irrigation in North Carolina[1]

J. I. Davidson, Jr.[2*], W. J. Griffin [3], M.C. Lamb[4], R. G. Williams[5], and G. Sullivan[6]

ABSTRACT

During crop years 1989-1992 EXNUT concepts and a version of EXNUT modified for North Carolina conditions were evaluated. This version was revised and evaluated on 20-25 peanut fields during crop years 1993, 1994, 1995, 1996, and 1997 when average yields of 4360, 4890, 4640, 4530, and 4770 kg/ha, respectively, were obtained. These yields averaged 880 kg/ha higher than average yields produced on these irrigated fields prior to 1993 and 1660 kg/ha higher than the average county yields during 1993-1997. The farmers and county agents reported that irrigation scheduled by EXNUT provided an estimated 500 kg/ha increase in yields. Costs of running EXNUT were estimated at $5.14/ha. Using these estimates, net returns from using EXNUT instead of normal irrigation scheduling by the farmer was $272.76/ha. Average compliance of farmers with EXNUT water scheduling recommendations was 85 and 75% for wet years (1994 and 1996) and dry years (1993, 1995, and 1997), respectively. On the average, a 71% or higher compliance with EXNUT recommendations on fields with sandy- and medium-type soils resulted in yields greater than 4480 kg/ha, making irrigation of peanuts feasible in these fields at a world market price as low as $350 per metric ton. Every percentage point increase in compliance with EXNUT recommendations on these fields resulted in an increase in yield of 50 and 110 kg/ha during wet and dry years, respectively. Yields from fields with heavy type soils averaged only 3850 kg/ha because of excessive disease and harvest losses. On the average, peanuts can be produced on this heavy-type soil at world market prices of $410/metric ton if compliance with EXNUT recommendations is at least 80%. This 9-yr study is an example of how expert systems can be transferred through cooperation of researchers, extension specialists, and users.

Key Words: Expert system, computer decision aide, peanut production management, scheduling peanut irrigation, peanut management system, geocarposphere (GCS) temperature.

Numerous studies have addressed the acceptance of computer technology and expert systems in agriculture. Amponsah (1995) concluded that the adoption rate of computer technology in North Carolina was positively related to farm size and education level and inversely related to age. The study further concluded that increased farm management efficiency from better use of information will contribute to increased competitive-

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[2]Mech. Eng., USDA, ARS, Nat. Peanut Res. Lab., Dawson, GA 31742.
[3]Bertie County Ext. Director, Windsor, NC 27983.
[4]Res. Fellow, Dept. of Agric. Econ. and Rural Soc., Auburn Univ., Auburn, AL 36849.
[5]Res. Tech., Federal-State Inspection Service, Dawson, GA 31742.
[6]Ext. Spec. (Retired), North Carolina State Univ., Raleigh, NC 27695.
*Corresponding author.

ness. Gum and Blank (1990) found that expert systems provide greater educational impact and are more cost effective than traditional extension approaches. By providing another knowledgeable source of information, expert systems increased farmers' confidence in making decisions 91% of the time (Smith *et al.*, 1988). Reduced acceptance of many expert systems was generally linked to faulty implementation rather than technical performance issues (Gill, 1992). Several expert systems are being developed for managing the peanut production, marketing, and post-harvest systems (Davidson *et al.*, 1995).

EXNUT, an expert system designed to manage peanut irrigation, was evaluated in a 9-yr study in North Carolina. The objectives of the study were to evaluate the concepts developed in the Georgia version of EXNUT, develop a version for virginia-type peanuts grown in North Carolina, and validate the new version over a 5-yr period.

In a 4-yr study (1980-1983) in Virginia by Wright *et al.* (1986) using a water balance model described by Powell *et al.* (1981) and Ritchie (1972, 1973) to schedule irrigation, irrigation of peanuts was not feasible. Peanut yields averaged 4562 and 4250 kg/ha for nonirrigated and irrigated plots, respectively. The cooperating extension agents and farmers in this experiment had similar experiences and prior to this study had averaged only about 780 kg/ha above the dryland and county yields (mostly nonirrigated). To justify the cost of irrigation, yields that averaged at least 800 kg/ha above the county yields were required. Since the peanut quota market price system was at risk, it was desirable that irrigation provide enough increase in yields to make peanut irrigation in North Carolina economically feasible to producing peanuts for the world market. The objective of this paper is to present information and data contributing to the modifications in EXNUT during 1989-1992 and to analyze the performance of EXNUT during the 5-yr validation period (1993-1997) in terms of making irrigation feasible for producing peanuts in North Carolina at world market prices.

Materials and Methods

The basic structure of EXNUT and how it uses yield potential, irrigation capacity, soil type, water thresholds, geocarposphere (GCS) temperature, eight time periods, variety and other variables to determine the best irrigation strategy is described by Davidson *et al.* (1995). Prior to 1989, the Georgia EXNUT version was modified for anticipated North Carolina conditions to allow a longer fruit addition period (e.g., 50 versus 40 d) and a 5- to 10-d later initiation of intensive irrigation considerations [e.g., 50-55 d after planting (DAP) versus 40-45 DAP]. These revisions were needed because accumulated heat units in North Carolina normally lag 5-10 d behind accumulated heat units in Georgia. The revised program was supplied to extension agents in Bertie, Edgecombe, Gates, Hertford, and Martin counties. These extension agents initially selected one or more farmers to gather data for EXNUT in one or more peanut fields. The basic data required to run EXNUT included (a) field name, (b) run date, (c) planting date, (d) soil type, (e) yield potential (based upon maximum fruit load), (f) crop rotation, (g) variety, (h) irrigation system capacity, (i) fruit initiation date, (j) canopy coverage [(canopy width ÷ row width) × 100], (k) water records accounting for runoff, (l) maximum and minimum GCS temperature, (m) presence or absence of visual plant stress, (n) probability of rain in next 2 d, (o) whether or not leaf spot disease was present, (p) date of last fungicide application, and (q) whether or not there had been 2 consecutive days having more than 10 hr of leaf wetness (based upon water and heavy dew records) during the last 10 d. EXNUT recommendations included (a) whether or not to irrigate, (b) when to run EXNUT again, (c) the amount of irrigation needed, (d) whether or not to apply an approved fungicide for leaf spot control, (e) if there was a need to scout for high or low temperature pests, (f) reasons for decision (optional), and (g) explanation of terms and strategy (optional). Extension agents were experienced in the use of tensiometer and soil moisture blocks. The extension agents and farmers irrigated on their best judgment using soil temperatures, and/or soil moisture blocks and the knowledge of the reasons for EXNUT recommendations. The farmers and county agents were not committed to following EXNUT recommendations, but were committed to evaluating the recommendations and reasons for the recommendations. After the final decisions were made and compared to EXNUT recommendations, the reasons for disagreeing with EXNUT recommendations were recorded by the extension agents. This procedure allowed the extension agents and research scientists to evaluate the new concepts and irrigation strategies used by EXNUT and to provide a basis for improvement.

Farmers reported the final yields and grade data as well as their constructive criticism of EXNUT. A limited number of samples were evaluated to verify maturity, grade and market quality.

During 1993-1997, 20-25 commercial fields were selected each year to provide a more intensive evaluation of EXNUT for virginia-type peanuts produced in North Carolina. This study was different from the earlier study in that the farmers and county agents were not committed to following EXNUT recommendations in the earlier study but were committed in the latter study. Scouting methods and equipment are described by Davidson (1995). After each year, yield and compliance data were analyzed and slight adjustments made to improve the performance of EXNUT and to test peanut irrigation hypothesis as to the benefits of using EXNUT for making peanut irrigation in North Carolina economically feasible for producing virginia-type peanuts for the world markets. Yields were determined by dividing the net farmers' stock weight obtained from the official grade sheets by the total acreage of the field. The extension agents and farmers had expressed a desire for EXNUT to help approach yields of 4480 kg/ha on their high yielding fields and to consistently average 800 kg/ha above Bertie County yields (mostly nonirrigated fields). Rainfall and irrigation amounts were measured by rain gauges. An average location was selected in each field for the soil thermometer and one rain gauge by observing the variation in soil types and elevation and by finding a location where the GCS temperature was average for the field. Locations near or far away from the pivot or traveler were excluded. A rain gauge outside the field recorded the rainfall. EXNUT bases its decisions on effective water [(rainfall + irrigation) - runoff]. In this study, runoff was assumed to be zero. The fields were visited one to three times a week by the county agent's technician to collect the basic data described above. The frequency of visits was determined by EXNUT strategy that require more frequent visits during the fruiting period (e.g., 45-95 DAP). The county agent entered the data and the probability of rain into the EXNUT program and relayed by phone EXNUT recommendations to the farmers. Fruit initiation date (FID) was determined by observing the date of first flush of blooms or by pulling up three to five plants at three locations in each field and counting the fruit indicators (pegs + pods) on all plants and entering the data into EXNUT to calculate FID.

EXNUT calculates FID = X by the following formula:

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

Y = Date field was observed.

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

P_o = Average number of pods per plant.

Visual stress was observed by visits to the field at 4-6 p.m. or by measuring the depth of the penetrometer when applying 800 N (180 lb) force rod in five to 10 locations tested in the non-traffic middle. If the penetrometer rod depth was shallower by 23 cm or more than the penetrometer rod depth when soil moisture is at field capacity, then stress was assumed to occur at 4-6 p.m.

Results and Discussion

Irrigation in North Carolina is primarily from surface water. Most of the irrigated peanut production in North Carolina is concentrated along the Roanoke, Cashie and Chowan rivers with Bertie County having most of the irrigated acreage. Fortunately, the North Carolina geographic peanut growing region usually receives near adequate rainfall but the pattern and timing of rainfall is variable and often nonconducive to producing maximum yields.

During 1989-1992, a wide range of soils and management strategies were evaluated. Eighteen fields scattered over seven counties were used in these evaluations. Soils were similar to Georgia soils except a few fields in North Carolina had Lenoir and Craven type soils that had poor infiltration, drainage, and tillage characteristics. The fields were visited by researchers during midseason and detailed information was obtained pertaining to the differences in peanut culture in North Carolina as compared to Georgia. The major differences other than peanut varieties and soil characteristics were in peanut diseases and disease control. To be compatible with EXNUT strategy, the Cooperative Extension specialists grouped the virginia-type peanut varieties according to early maturing (VA-C 92R, VA-C 93, NC 7, and NC-V11) and medium maturing varieties (NC 6, NC 9, NC 10C, and VC-1) and grouped the soils into sandy (Bonneau, Conetoe, Seabrook, Tarboro, Wickham) and medium-heavy type (Ahavista, Augusta, Craven, Doque, Exum, Goldsboro, Lenoir, Lynchburg, Nahunta, and Norfolk) classifications. The soils were primarily classified by presence (medium-heavy) or absence (sandy) of clay (<15%) in the top 76-cm layer. In addition to the common peanut diseases in Georgia, North Carolina had two additional diseases, *Cylindrocladium parasiticum* Crous Wingfield & Alfenas [Cylindrocladium black rot (CBR)] and *Sclerotinia minor* Jagger (Sclerotinia blight) that impact yield, quality, and economic returns, especially during cool wet periods.

CBR and Sclerotinia blight were especially severe during 1989 and 1992. Like most diseases, the earlier the incidence, the more the negative impact. Most North Carolina farmers used chemical controls for these two diseases. These farmers also used the Virginia-North Carolina Leaf Spot Advisory for controlling early and late leaf spot. The use of geocarposphere (GCS) temperature by EXNUT to alert the grower to scout for certain pests and to manage irrigation to help control the environment appeared to be even more effective in North Carolina than in Georgia. The cooler ambient temperatures in North Carolina attended by irrigation promoted more disease pressure and lower maturation rates than observed in Georgia. When maximum and minimum GCS temperatures decreased below 26.6 and 21.1 C, respectively, EXNUT would provide a pest alert to scout and consider applications of pesticides and would use a conservative irrigation strategy to allow the GCS temperatures to increase. Minor differences in North Carolina and Georgia peanut culture included more use in North Carolina of subsurface drainage systems, manganese foliar fertilizer for peanuts grown on deficient soils, and more land plaster for the larger virginia-type peanuts. These minor differences required no changes in EXNUT. During 1989-1992, the validity of using the maximum-minimum soil temperature thermometers, the eight time periods of irrigation relative to planting and fruit initiation, and the use of minimum and maximum cumulative threshold water curves were evaluated as well as the cultivar, soil, and yield potential groupings of each field. A typical evaluation of the maximum-minimum soil temperature concepts are presented in Fig. 1 and Table 1. The tensiometer readings were made but not recorded prior to 81 DAP. The tensiometers did not indicate a need to irrigate until 122 DAP, but EXNUT recommended irrigation 75 DAP to stop the rising GCS temperature. The primary advantages of soil thermometers over soil tensiometers were the thermometers indicated the need for irrigation earlier to lower the soil temperature to induce pegging and the thermometers indicated irrigation was not needed when cool soil temperature disease (Sclerotinia blight and/or CBR) were active and/or when maturation rates were low. Other advantages of the soil thermometers were that they could be placed in a more representative site by using a portable digital soil thermometer than could the soil moisture sensors. The soil thermometers continued to operate in very dry conditions, whereas the soil tensiometer failed to perform because they lost their vacuum and soil tension reading. The optimum soil temperatures for providing maximum yield and quality reported by Davidson *et al.* (1991) were found to be valid for the

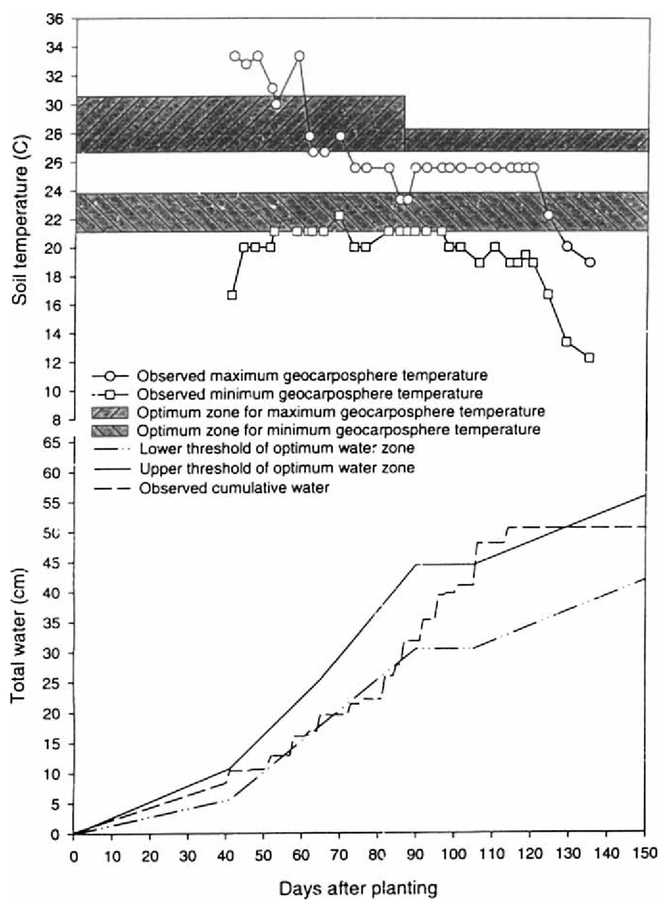

Fig. 1: Typical cumulative water and soil temperature plots for crop year 1990 high yielding field as compared to EXNUT's thresholds and optimum soil temperature zones used during crop year 1990.

North Carolina peanut-growing region. The optimum zone for maximum soil temperatures was 26.6-30.5 C prior to 90% canopy coverage and 26.6-28.3 C when canopy coverage ≥ 90%. The optimum zone for minimum soil temperatures was 21.1-23.9 C. From about 1 Sept. to harvest, it was usually difficult to maintain the soil temperatures in the optimum zones because of cool ambient temperatures but, by maintaining the GCS temperatures as high as possible, the risk of Sclerotinia blight and CBR and low maturation rates were minimized.

A description of the eight time periods used in EXNUT is presented in Table 2. Based on observations by the farmers and extension agents, the time periods and irrigation strategies appeared valid during 1989-1992, but questions still existed as to the date for initiating intensive irrigation scheduling and for the beginning of a drying-out period. The initiation of irrigation according to cultivar was questioned because the farmers had a tendency to be late with the first irrigation. This lateness delayed fruiting and maturation thereby increasing the risk of immaturity and freeze damage especially for the medium and late maturing varieties. The initiation of the drying-out period was questioned because of the risk of reducing fruit load by stressing the plant during the fruit addition period.

EXNUT uses cumulative water thresholds to outline the minimum and maximum cumulative water requirements to achieve the desired yield potential. Evaluation of the cumulative water thresholds as shown in Fig. 1 showed this concept to be valid because EXNUT used the upper water threshold to prevent excessive irrigation during wet years (1989 and 1992) and the low water threshold to insure adequate irrigation during the dry years to help keep the GCS temperatures in the optimum zone, and to alert the user to unusual situations such as improper location or calibration of thermometers or poor root system. Even though excessive rainfall and cool temperatures may reduce the GCS temperatures below the optimum, the higher the GCS temperatures are maintained, the lower the risk of immaturity and disease.

The variety and soil groupings appeared to be valid. Yield potential varied according to location, variety, crop rotation, fertility, irrigation system capacity, and soil types. The yield potential of the highest yielding fields as provided by the farmers and extension agents were no more than 4480 kg/ha. However, based upon observed fruit loads, final yields, and harvest loss estimates during 1989-1992 using EXNUT concepts, it appeared that the 5600 kg/ha used by EXNUT to divide the high and average yield potential fields was valid. Thus, all fields were considered to have a maximum yield potential that was ≥ 5600 kg/ha except those with poor crop rotation, inadequate irrigation capacity, poor fertility, or soils types with low water infiltration rates such as Craven and Lenoir types. EXNUT uses a more conservative irrigation strategy (less water) for fields having a maximum yield potential < 5600 kg/ha.

To validate the results of the 1989-1992 study, a validation study was conducted during 1993-1997. Varieties and percentages of fields planted to each were NC 7 (39.7%), NC-V11 (25.6%), NC 10 (18.2%), VC 1 (6.6%), VA-C 92R (5.8%), NC 9 (2.5%), and NC 6 (1.7%). Some performance data for EXNUT during CY 1993-1997 are presented in Tables 3 and 4. Total amounts of rainfall were near adequate during 1995 and excessive during 1996. Rainfall amounts were excessive during the early and late seasons of 1996, the early season during 1993 and 1995, and the late season of 1994 and 1997. Late season rainfall near harvest resulted in excessive yield losses especially during 1994, 1996, and 1997. Excessive harvesting losses occurred on 11, 26, and 54% of the sandy, medium, and heavy soils, respectively. Reasons for differences were later planting and later harvesting dates and higher disease pressure that weakened the pod stems for the medium and heavy soils. Average losses were about 350, 500, and 700 kg/ha for the sandy, medium, and heavy soils, respectively. Excessive losses exceeded these values by more than 50%. During 1993, 1995, and 1997, rainfall was very deficient during the primary fruit-addition period (from fruit initiation to 50 d after fruit initiation). During these 3 dry years, approximately 65% of the fields exceeded the 4484 kg/ha yield potential provided by the farmers and extension agents for the fields with sandy- and medium-type soils. Several low-yielding fields had limited irrigation capac-

Table 1. Typical comparison of soil thermometers readings with soil tensiometers (CY 1992, Conetoe soil, NC-V11, poor crop rotation).

Days after planting	Water		Soil temperature		Soil tension								
					Site 1 depth (cm)			Site 2 depth (cm)			Site 3 depth (cm)		
	Rainfall	Irrigation	Max.	Min.	15.2	30.6	45.7	15.2	30.6	45.7	15.2	30.6	45.7
	cm		C		centibars								
17	3.60	0	27.5	20.9	-	-	-	-	-	-	-	-	-
18	0.30	0	22.6	18.2	-	-	-	-	-	-	-	-	-
19	0.18	0	18.7	16.5	-	-	-	-	-	-	-	-	-
21	0.03	0	25.3	14.3	-	-	-	-	-	-	-	-	-
25	1.07	0	19.8	17.1	-	-	-	-	-	-	-	-	-
28	0.43	0	18.7	16.5	-	-	-	-	-	-	-	-	-
29	1.90	0	19.8	22.0	-	-	-	-	-	-	-	-	-
30	0.05	0	23.7	18.7	-	-	-	-	-	-	-	-	-
34	0.38	0	22.6	20.4	-	-	-	-	-	-	-	-	-
35	0.56	0	25.3	19.8	-	-	-	-	-	-	-	-	-
39	2.82	0	28.1	24.2	-	-	-	-	-	-	-	-	-
40	0.03	0	27.5	23.1	-	-	-	-	-	-	-	-	-
50	1.04	0	29.7	23.7	-	-	-	-	-	-	-	-	-
51	1.75	0	24.8	20.9	-	-	-	-	-	-	-	-	-
54	0.43	0	27.5	19.8	-	-	-	-	-	-	-	-	-
55	1.07	0	28.1	22.6	-	-	-	-	-	-	-	-	-
56	4.40	0	26.4	23.1	-	-	-	-	-	-	-	-	-
62	0.03	0	27.5	24.8	-	-	-	-	-	-	-	-	-
64	0.15	0	28.1	24.8	-	-	-	-	-	-	-	-	-
65	0.03	0	27.5	24.2	-	-	-	-	-	-	-	-	-
66	1.60	0	26.4	25.3	-	-	-	-	-	-	-	-	-
75	0	1.90	29.2	25.3	-	-	-	-	-	-	-	-	-
77	0	2.18	29.7	24.2	-	-	-	-	-	-	-	-	-
81	1.78	0	28.6	23.7	13	8	10	12	14	22	12	25	42
83	0.51	0	28.6	24.8	21	10	13	30	24	23	30	40	44
85	1.14	0	-	-	-	-	-	-	-	-	-	-	-
87	0	0	27.5	23.7	16	18	20	30	36	27	8	12	14
88	3.90	0	28.1	24.2	10	4	5	8	10	10	5	8	10
90	0	0	26.4	23.7	12	8	9	12	12	14	10	10	12
94	2.8	0	27.5	21.5	9	10	13	4	9	16	-	-	-
95	0.13	0	27.5	23.7	10	7	15	8	10	18	5	9	12
97	1.52	0	27.5	22.6	9	10	13	4	9	16	-	-	-
101	1.27	0	-	-	-	-	-	-	-	-	-	-	-
104	3.18	0	27.0	22.0	8	0	2	2	8	5	2	2	5
107	12.70	0	-	-	-	-	-	-	-	-	-	-	-
109	2.54	0	25.3	22.0	10	47	5	-	-	-	-	-	-
116	1.52	0	26.4	19.8	10	8	10	30	15	14	10	9	10
119	1.07	0	-	-	-	-	-	-	-	-	-	-	-
122	0	0	26.4	18.7	10	22	24	45	48	18	14	55	16
126	0	0	26.4	19.8	22	36	30	82[a]	74[a]	24	70	44	12
129	2.10	0	26.4	19.8	9	8	22	8	0	32	7	10	9
142	2.79	0	27.5	17.6	8	40	62	5	82	68	10	10	4

[a]Soil was so dry (127-129 DAP) at this location and depth that the soil tensiometer lost its tension.

ity and were not irrigated during the primary fruit-addition period according to EXNUT recommendations, especially during 1993, 1995, and 1997. In dry years (1993, 1995, and 1997), EXNUT recommended irrigation on a timely schedule, but there was often a lag of several days between the recommendation and the application of water especially on the startup of the intensive irrigation periods. This problem was especially severe during 1993. Thus prior to 1994, the EXNUT program was changed to start considerations for intensive irrigation scheduling 45 DAP for all cultivars rather than waiting to 50 DAP for the medium maturity cultivars. After 1994 there was some concern by the Coop. Ext. Serv. that the drying-out period beginning 50 d after fruit

Table 2. Summary of the evaluation of eight time periods for scheduling irrigation.

Time period	GA EXNUT strategy	NC strategy
(1) Prior to planting	Irrigate only enough to wet the dry soil layers that would reduce pest control, emergence, or root growth.	Irrigation strategy should be even more conservative than GA because of the higher risk of rainfall and CBR.
(2) Planting to 10 d after planting (DAP)	Do not irrigate unless there is insufficient moisture for emergence or to activate pesticide.	The same as GA strategy except for additional warnings of the risk of CBR and excessive rainfall.
(3) 11 to 25 DAP	Check for hardpan with penetrometer rod and irrigate only to induce emergence, activate herbicide, or to alleviate hard pan.	Should be same as GA strategy except for additional concerns for risk of CBR and excessive rainfall.
(4) 26 DAP to fruit initiation (FI)	Do not irrigate unless there is a serious problem with crown rot (CR), or lesser corn stalk borer (LCSB), or herbicide injury.	Should be more conservative than GA strategy because CR, LCSB, and observed herbicide injury problems are less serious in NC, but CBR and southern corn root worm (SCRW) are more serious in NC.
(5) FI to FI + 20 d	Irrigate to bring soil temperatures into the optimum zone for pegging and to provide sufficient water for field yield potential.	The same as GA, except this period may need extending to allow for longer fruiting periods needed by virginia-type peanut cultivars.
(6) 21 d after FI to 40-50 d after FI	Irrigate extensively to keep soil temperatures in the optimum zone for fruit addition and to supply enough water to obtain field yield potential.	The same as GA except this period may need to be extended to allow for longer fruit addition period needed for the cooler NC environment.
(7) Drying-out period of 8-14 d	Do not irrigate except to prevent high soil temperatures or to relieve plant stress.	The same as GA except this period may need to be earlier or later depending upon water availability, soil temperatures, and CBR and Sclerotinia pressures.
(8) End of drying-out period to harvest	Irrigate only as needed for harvest to prevent high soil temperatures, plant stress, and to provide sufficient water for maturation. Avoid irrigation during periods of low soil temperature. Keep a reservoir for rainfall to minimize excessive soil moisture especially near harvest time.	The same as GA except a period of about 2 wk may be needed immediately after the drying-out period to insure sufficient moisture for maturation. After these 2 wk the NC strategy should be more conservative because of higher risks of CBR, Sclerotinia blight and digging losses resulting from a delay in harvesting.

initiation (FI) was too early. Thus, prior to 1995, the drying-out period was moved back to about 70 d after FI. Analysis of the 1995 data showed that the drying-out period should be earlier than the initial strategy, but the timing should be based upon soil temperatures and cumulative water curves. In addition, intensive irrigation scheduling should be resumed for about 14 d immediately after the drying-out period to minimize the need for irrigation later in the season when the maximum GCS temperature drops below 26.6 C. Based upon these results, an additional period of irrigation scheduling was implemented and the new water curves were formulated (Fig. 2).

Typical water curves and soil temperatures for a representative fields is shown in Fig. 3. Since the plots of the cumulative water and soil temperatures relative to the threshold values are so important for indicating the risk associated with drought, excessive water, and pest, EXNUT was modified after 1996 to provide an option for viewing and printing these plots. The soils (e.g., Craven,

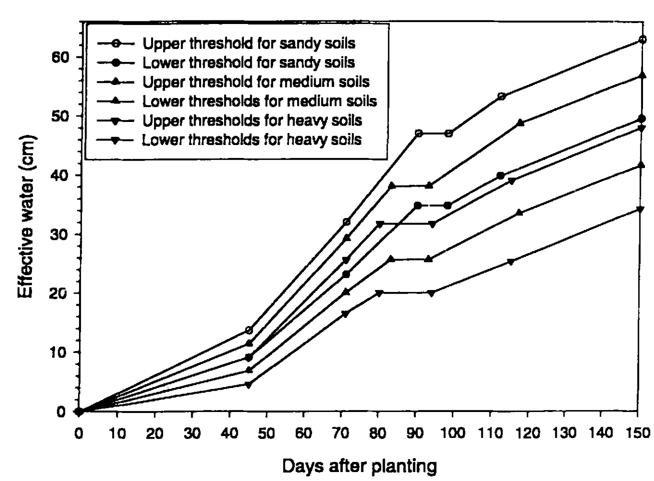

Fig. 2: Water thresholds for North Carolina soils as indicated by crop year 1993 and 1994 high yields.

Table 3. Summary of some EXNUT field data for North Carolina (1993-1997).

Item	No. fields	Crop rotation		Planting date		Fruiting DAP[a]	
		Range	Average	Range	Average	Range	Average
		------yr-------					
Sandy soils[b]							
1993	11	1-2	1.5	29 Apr.-13 May	5 May	48-55	51.3
1994	7	1-2	1.4	27 Apr.-11 May	2 May	43-64	56.4
1995	11	1-2	1.5	28 Apr.-11 May	4 May	45-71	53.3
1996	13	1-3	1.7	29 Apr.-9 May	3 May	50-61	53.0
1997	11	1-2	1.8	1 May-8 May	4 May	53-63	56.4
Medium soils[c]							
1993	11	1-3	2.0	7 May-22 May	13 May	42-53	48.6
1994	10	1-2	1.7	21 Apr.-14 May	8 May	47-71	54.8
1995	12	1-3	2.3	28 Apr.-19 May	8 May	43-60	50.5
1996	9	2-3	2.2	4 May-15 May	11 May	38-59	49.7
1997	10	2-3	2.1	3 May-16 May	9 May	53-63	57.5
Heavy soils[d]							
1993	3	2-3	2.5	4 May-13 May	9 May	50-55	52.0
1994	3	2-2	2.0	10 May-11 May	11 May	50-58	54.0
1995	2	2-3	2.5	9 May-18 May	13 May	46-51	48.5
1996	2	2-3	2.5	11 May-15 May	13 May	43-48	45.5
1997	4	2-3	2.5	7 May-15 May	12 May	53-62	56.0

[a]DAP = days after planting.
[b]Sandy soils are defined as sandy loams or loamy sands having less than 15% clay in the top 76 cm.
[c]Medium soils are defined as sandy loams or loamy sands with at least 15% clay in the top 76 cm and having good water infiltration properties.
[d]Heavy soils are defined as very dense soils having at least 15% clay and poor water infiltration properties.

Table 4. Summary of EXNUT performance (1993-1997).

Item	Rainfall			Irrigation			Compliance[a]			Pod yield[b]		
	Range	Average	S.D.	Range	Average	S.D.	Range	Average	S.D.	Range	Average	S.D.
	------cm------			------cm------			------%------			-------kg/ha------		
Sandy soils[c]												
1993	21.7-39.0	27.2	5.5	8.6-24.9	17.4	4.4	55.6-78.6	70.9	6.6	3640-5010	4480	374
1994	32.9-38.5	36.1	1.9	3.2-15.2	10.7	3.9	63.0-93.0	79.8	9.6	3980-5620	4890	560
1995	43.1-60.7	52.3	5.0	10.9-18.5	14.4	2.3	64.0-89.0	73.9	8.3	3920-5380	4560	476
1996	66.0-82.3	74.0	4.7	1.3-7.6	3.4	1.9	68.8-93.5	81.6	7.6	2520-5710	4600	985
1997	29.5-48.3	40.1	5.8	7.6-18.0	12.6	3.3	63.9-82.9	74.1	5.2	3060-6690	4830	951
Grand avg								**76.1**			**4670**	
Medium soils[d]												
1993	22.1-41.3	29.6	6.7	7.9-20.6	13.9	4.2	55.2-81.5	71.5	8.5	2830-5240	4370	727
1994	31.8-44.6	37.3	4.8	1.8-14.0	5.5	3.8	74.2-93.3	85.7	6.9	4020-5760	5100	543
1995	47.2-63.1	53.7	5.0	6.6-16.8	12.1	3.1	65.0-93.0	81.3	8.1	3320-5810	4750	724
1996	59.2-75.7	68.1	6.0	1.8-3.8	1.9	1.5	69.4-96.8	90.4	9.0	3410-5780	4690	708
1997	23.4-38.1	29.4	5.1	5.6-15.2	9.9	3.1	73.5-88.6	81.5	5.0	4480-6590	5220	671
Grand avg								**82.1**			**4830**	
Heavy soils[e]												
1993	27.1-32.0	30.3	2.8	4.4-11.4	8.7	3.8	56.6-81.5	69.2	13.0	3530-4050	3790	368
1994	28.3-37.2	33.2	4.5	1.0-7.9	4.4	3.5	86.7-90.0	87.9	1.8	3260-5530	4220	1170
1995	46.5-56.9	51.7	7.4	5.1-15.0	10.1	7.0	72.0-74.0	73.0	1.4	3940-4370	4150	302
1996	67.6-77.0	72.3	6.4	0.0-3.0	1.5	2.1	87.1-96.8	92.0	6.9	2350-4480	3420	1513
1997	24.9-33.3	30.2	3.7	3.3-8.4	5.6	2.2	74.3-80.0	77.9	2.7	2920-4480	3650	656
Grand avg								**80.0**			**3850**	

[a]Percent compliance with recommendations by EXNUT to irrigate or not to irrigate.
[b]Average county yields (mostly nonirrigated) were 2564, 3522, 2726, 2922, and 2915 kg/ha for 1993, 1994, 1995, 1996, and 1997, respectively. Average irrigated yields on these fields prior to 1993 were approximately 600 kg/ha higher than the average county yields.
[c]Sandy soils are defined as sandy loams or loamy sands having less than 15% clay in the top 76 cm.
[d]Medium soils are defined as sandy loams or loamy sands with at least 15% clay in the top 76 cm and having good water infiltration properties.
[e]Heavy soils are defined as very dense soils having at least 15% clay and poor water infiltration properties.

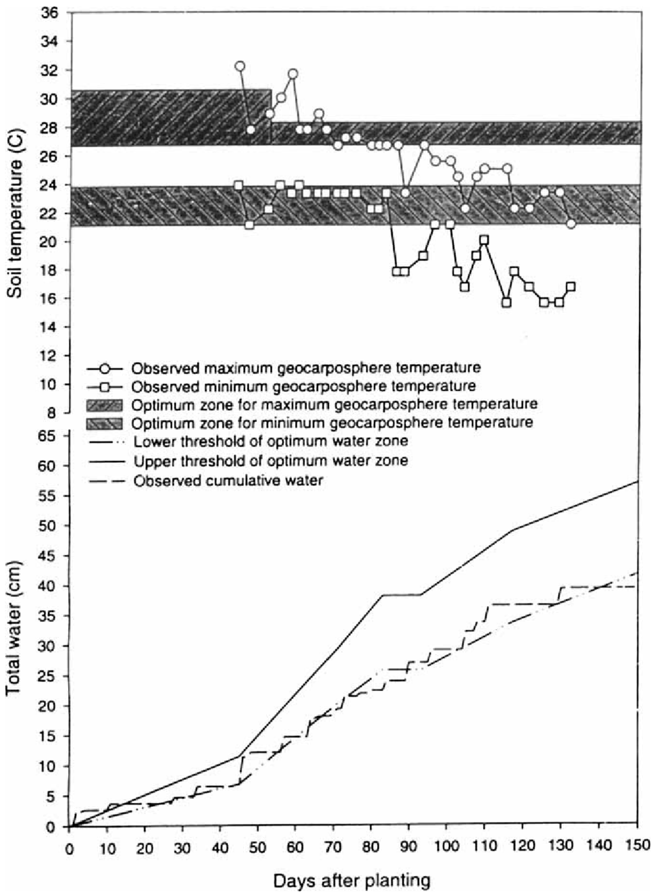

Fig. 3: Typical cumulative water and soil temperature plots for crop year 1996 high yielding field as compared to EXNUT's threshold and optimum soil temperature zones used during 1995, 1996, and 1997.

Lenoir) with poor water infiltration rates were difficult to irrigate and EXNUT application rates were reduced to a maximum of 1.27 cm per application. When the cumulative water exceeded the upper threshold, EXNUT was 1-5 d early in recommending irrigation during 1996. Thus, prior to 1997, EXNUT excess water rules were revised to require a check of water during last 21-28 d as well as normal 3-, 5-, 7-, 10- and 14-d checks. In addition, penetrometer rod or plant stress checks were implemented to verify high risk excess water decisions. The farmers and cooperative extension personnel were very pleased with the performance of EXNUT. During 1993-1997, the yields from the EXNUT-managed fields averaged 4640 kg/ha, compared to an average of 2980 kg/ha for the Bertie County yield. When compared to prior irrigated yield history of these fields (780 kg higher than county yields), EXNUT and improved production practices provided an average [4640 - (2980 + 780)] = 880 kg/ha yield increase. T-tests were used to determine if the mean differences between the EXNUT and county yields as well as the differences between the EXNUT and traditional irrigated yields were significantly different from zero. The results indicate that EXNUT yields were significantly higher than county yields (P = 0.05) in each year. EXNUT yields were significantly higher than traditional irrigated yields in 1993, 1995, and 1997 (P = 0.05) and 1996 (P = 0.10). No significant differences were found between EXNUT and traditional irrigated yields in 1994. Significant differences (P = 0.05) in means resulted when comparing EXNUT yields to county yields and traditional irrigated yields during the 1993-1997 period. During 1993-1997, the farmers and extension agents estimated that the use of EXNUT provided at least a 500 kg/ha yield increase over traditional irrigation scheduling, slightly more than the 340 kg/ha reported for Georgia by Davidson *et al.* (1995). Incorporating the collection of the field data (including labor, mileage allowance, rain gauge, thermometers) and running the program, the cost of EXNUT was estimated to be $5.14/ha. Using the 500 kg/ha increase and a weighted average price of quota and contract additionals, the estimated net return from using EXNUT was $242.45/ha.

Regressions of the percentage compliance with EXNUT's recommendations (to irrigate and not to irrigate) on yield for the most widely used varieties (NC 7, NC-V11, and VA-C 92R), fields with sandy- and medium-type soils, 1- to 2-yr crop rotations, and average harvest losses are presented in Fig. 4. These regressions show that for every 1% increase in compliance will result in an average increase of 52 and 115 kg/ha on wet and dry years, respectively. Thus, by complying with EXNUT recommendations 71% of the time and using other good production practices, the North Carolina irrigated peanut producers should be able to compete at world market prices as low as $350.00/metric ton. The average yields of the heavy-type soils were only 3850 kg/ha when complying with EXNUT recommendations 80% of the time. Thus, competitive market prices for this EXNUT performance level for the fields with heavy soil would be $410/metric ton.

In summary, the Georgia version of EXNUT was revised for use in North Carolina to accommodate the higher risk of immaturity, additional severe soil-borne diseases (Sclerotinia blight and CBR) and excessive water. The higher risk in North Carolina required initiation

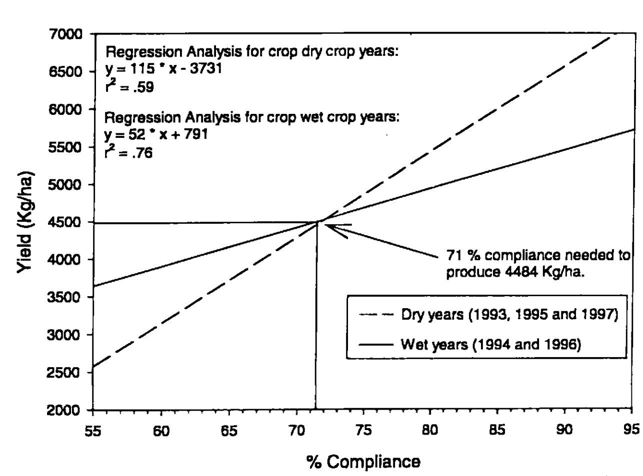

Fig. 4: Effect of compliance with EXNUT decisions on final yield of fields planted with NC 7, NC-V11, and VA-C 92R peanut varieties.

of intensive irrigation and dry-out periods earlier than expected thereby altering slightly the cumulative water thresholds. A high risk of excessive water and run-off also required revisions to the soil grouping and excess water rules. The basic EXNUT structure and strategy used in Georgia was generally valid for North Carolina, including the use of the same yield potential and GCS temperature criteria. Economic benefits of using EXNUT in North Carolina were more than the benefits reported for using EXNUT in Georgia. EXNUT and use of improved production practices provide positive benefits to the North Carolina irrigated peanut farmer, especially if a high percentage of EXNUT compliance is practiced. Improvements to EXNUT include the addition of economic and risk assessments, heat unit criteria, and adding more decisions relative to pest management. This 9-yr study is a good example of how technology contained in expert systems can be transferred through the close cooperation of researchers, extension specialists, and users.

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