Water Quality Impacts Associated With Peanut Culture in the Southern Plains[1]

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ABSTRACT

Water quality information associated with peanut (*Arachis hypogea* L.) culture is limited, but needed from both environmental and agronomic standpoints. In this study, we consider surface and ground water quality characteristics involved with conventional till (viz, moldboard plow) culture of irrigated peanuts. During a 3- and a 6-year study, sediment and associated nitrogen (N) and phosphorus (P) discharge in surface water runoff were measured from two similarly managed peanut watersheds in southwestern Oklahoma. Mean annual discharge from the Cobb fine sandy loam soil (Udic Haplustalf with 2% slope) was approximately 20 Mg ha^{-1} sediment, 18 kg ha^{-1} total N, and 5 kg ha^{-1} total P. Annual soluble N and P losses in surface water runoff tended to be small (< 1 kg ha^{-1}). Even so, concentrations of soluble P in runoff frequently exceeded recommended eutrophication guidelines. Successful prediction of soluble P, particulate P, and particulate N losses was achieved using appropriate kinetic desorption and enrichment ratio techniques. Concentrations of N and P in the watersheds' ground waters posed no particular water quality problems. Sampling for pesticides associated with peanut culture was made during the middle and at the end of the study, but none were detected in surface or ground waters. Overall, additional attention should be directed to reducing soil erosion. This may be done by judicious use of cover crops, and/or reduced tillage practices.

Key Words: Surface water runoff, ground water, sediment, erosion, nitrogen, phosphorus, pesticides.

Nonpoint source contamination of water resources by agricultural chemicals is recognized as one of the Nation's major water quality concerns (USEPA, 1984). The general goal is to maintain an economically acceptable crop yield, while minimizing potential surface and ground water contamination by agricultural chemicals, such as N, P, and pesticides.

Relative to more humid areas, the Southern Plains (i.e. New Mexico, Oklahoma, and Texas) has received limited attention in regard to water quality problems associated with agriculture. Some earlier work in the Southern Plains focused on water quality impacts associated with grassland and grazing situations (Blackburn *et al.*, 1982; Glover *et al.*, 1983; Kissel *et al.*, 1976). More recent work has focused on water quality impacts due to soil, N, and P loss in surface and ground water from sorghum [*Sorghum bicolor* (L.) Moench] (Sharpley *et al.*, 1991) and wheat (*Triticum aestivum* L.) culture (Smith *et al.*, 1991).

One important agricultural crop about which general water quality information is particularly lacking is peanuts (*Arachis hypogaea* L.). They are a major cash crop of the Southern Plains, and are often grown on permeable, coarse-textured, erosive soils. Also, much of the peanut hectarage receives additional water in the form of irrigation.

This paper presents a study of the surface and ground water quality impacts of peanut culture for two watersheds in southwestern Oklahoma from 1982 through 1990. Peanuts were grown clean-tilled in rotation, and water quality factors considered include sediment, N and P forms, and pesticides.

Materials and Methods

Watersheds

Pertinent information about the two peanut watersheds and their management is given in Table 1. The watersheds are located on Cobb fine

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sandy loam (fine loamy, mixed, thermic Udic Haplustalf) at the Caddo Research Station, Oklahoma Agricultural Experiment Station, near Fort Cobb in Oklahoma's major peanut producing area. Watersheds, FC-1 and FC-2, were in non-sequenced crop rotations involving primarily peanuts, grain sorghum, and wheat during the 10-year study period. Peanuts followed clean-tilled grain sorghum on FC-1, and clean-tilled grain sorghum or peanuts on FC-2. Only those years in which peanuts dominated the crop rotation are considered here. For the 2.1 hectare FC-1 watershed this involved three years (1983, 1985, and 1988), and for the 2.6 hectare FC-2 watershed six years (1982, 1983, 1984, 1986, 1988, and 1990). The watersheds were adjacent, with FC-1 and FC-2 having eastern and southern orientations, respectively.

Cultural practice for peanut production, typical for the area, included moldboard plowing (approximately 20 cm deep), disking, bedding, and clean tillage after planting. Fertilizer and pesticide applications were made according to soil test recommendations and potential for pest incidence. Sprinkler irrigation, obtained from nearby drilled wells, occurred 3-6 times per growing season, at a 10 cm-rate each time. Spanish-type peanuts were grown, and annual yields were in the order of 2500-2800 kg nuts ha^{-1}. Only the unshelled peanuts were removed from the watershed.

Field Sampling

Watershed runoff was sampled using precalibrated flumes equipped with waterlevel recorders. Generally, 5 to 15 samples were collected automatically with a pump sampler (Miller *et al.*, 1969) throughout an event. After comparison with the runoff hydrograph, samples for the subject watershed were composited in proportion to total flow to provide a single-event representative sample of liquid and sediment for chemical analysis.

Each watershed had one shallow observation well placed several meters upslope of the flume to obtain an associated sample of the field's ground water. The wells were cased, slot-screened, lidded, and the upper 2 to 6 m sealed with cement or bentonite slurry to prevent any direct surface inflow. Water table depths were approximately 15 m, and the drilled depths were approximately 20 m. The wells were bailed (2-3 saturated casing volumes) 1 day prior to sampling to ensure samples represented aquifer water. Sampling of the wells typically occurred 4 times each year, on a seasonal basis. All well and runoff samples were refrigerated at 4C from collection until analysis.

Soil samples for profile N characterization were collected by taking triplicate cores on each watershed. Five centimeter diameter cores were obtained in 15- to 30-cm increments to the 3 m soil depth, with the aid of a hydraulic sampler. Individual core increments were air-dried, sieved (2 mm), and stored in tightly sealed glass jars prior to analysis.

Surface soil samples (0-5 cm depth) for determination of soil nutrient contents used in the predictive runoff equations (Eqns. 1, 2, and 3) were collected annually in March at four sites near the flume of each watershed, composited, air-dried, sieved (2 mm), and stored in tightly sealed glass jars prior to analysis.

Laboratory Analysis

Sediment concentrations of the runoff samples were determined gravimetrically after evaporation of water. Aliquots of the respective composited runoff samples were centrifuged (27,160 g for 5 min) and filtered (0.45 μm) prior to soluble nutrient analysis. Total nutrients were determined on unfiltered composite runoff samples.

Chemical analyses for nitrate-N (NO_3-N), soluble ammonium-N (NH_4-N), and Kjeldahl N (TKN) in runoff and ground water were conducted using standard automated colorimetric methods described in Methods for Chemical Analysis of Water and Wastes (USEPA, 1979). Kjeldahl N represents primarily particulate organic N, but includes any NH_4-N present. Particulate N (PN) was calculated as the difference between TKN and soluble NH_4-N. Soluble P (SP) was determined by the colorimetric method of Murphy and Riley (1962) and total P (TP) by digestion of unfiltered samples with perchloric acid (O'Conner and Syers, 1975). Particulate P (PP) was calculated as the difference between TP and SP. Conductivity and pH were determined with a glass electrode.

Nutrient concentrations for runoff are reported as flow-weighted means. Nutrient discharge from individual storms was summed to calculate annual discharge. The U.S. Environmental Protection Agency publications (1973, 1976) were used as guides for water quality standards.

Nitrate-N and NH_4-N in soil samples were determined by extraction with KCl (Keeney and Nelson, 1982). Total Kjeldahl N was determined by the semi-micro procedure of Bremner and Mulvaney (1982). Available P content was determined using the Bray-1 procedure (Bray and Kurtz, 1945) and TP by digestion with perchloric acid (Olsen and Sommers, 1982). The concentration of P was measured on all neutralized filtrates of soil extracts by the method of Murphy and Riley (1962).

Pesticide analyses were conducted by the Oklahoma State Department of Agriculture Laboratory using EPA-approved gas chromatographic procedures. General analyses included determinations for phenoxy, organochlorine, and orthophosphate pesticides. Specific analyses included determinations for Bravo [tetrachloro -isophtalonitrile], Dual [2-chloro-N-(2-ethyl-6-methylphenyl)-N-(2-methoxy-1 methylethyl) acetamide], Furadan [2-3-Dihydro-2, 2-dimethyl-7-benzofuranyl methylcarbamate (CA)], Lorsban [0, 0-diethyl 0-(3, 5, 6-trichloro-2-pyridinyl) phosphorothioate], and Vernam [S-propyldipropylthiocarbamate].

Results and Discussion

Surface Water Runoff and Sediment Discharge

Mean annual hydrologic characteristics for the two watersheds are given in Table 2. In both cases, rainfall amounts during the study periods exceeded the long-term averages by 6 to 8 cm, so discharge may have been somewhat above "normal". However, no close relationships were evident among average annual rainfall, surface water runoff, and sediment discharge. For instance, watershed FC-1, had the greater amount of runoff, 13 cm, but the lesser amount of sediment discharge, 17,600 kg ha^{-1}. This contrasts to 9 cm and 22,200 kg ha^{-1} for watershed FC-2. Such a situation is considered to reflect the erratic timing, intensity, and distribution of natural rain in the area, over a variable time period. Irrigation had little effect on surface water runoff and sediment discharge, probably because applications occurred during dry periods of summer, when runoff potential was low. Overall, both surface runoff and sediment discharge associated with peanut culture were comparable to that for

Table 1. Field characteristics and management of peanut watersheds.

Watershed	Soil Type	Size	Approx. Slope	Study Period [1]	Total Events	Cultural Management [2]	Fertilizer Applied [3] N	Fertilizer Applied [3] P
		(ha)	(%)	(yr)			(kg ha^{-1} yr^{-1})	
FC-1	Cobb fsl	2.6	2	3	13	Moldboard plow, disk, bed,	15	13
FC-2	Cobb fsl	2.1	2	6	28	plant, and clean till	21	7

[1] FC-1; 1983, 1985, and 1988. FC-2; 1982, 1983, 1984, 1986, 1988, and 1990.

[2] Same management applies to both watersheds.

[3] Average N and P rates during years peanuts were grown.

Table 2. Mean annual and range of hydrologic characteristics for peanut watersheds.

Watershed	Rainfall			Runoff		Sediment Discharge	
	Long-term	Study Period					
	Mean	Mean	Range	Mean	Range	Mean	Range
	cm					kg ha^{-1}	
FC-1	76	84	63-103	13	6-18	17,600	10,200-23,400
FC-2	76	82	63-103	9	1-17	22,200	2,690-46,400

conventional dryland sorghum culture of these watersheds (12 cm and 16000 kg ha^{-1} yr^{-1}, respectively) (Sharpley *et al.*, 1991).

Nutrient Discharge

Flow-weighted, mean annual chemical characteristics of the runoff are summarized in Table 3. Both concentrations and quantities are given, and include N and P forms, pH, and specific conductance (to reflect general salt concentrations).

The concentration values are primarily of interest from a water quality standpoint and represent dissolved nutrient levels, except for TKN and TP, which are associated mainly with suspended sediment. Nitrate-N concentrations below 10 and 100 mg L^{-1} are considered acceptable for potable human and livestock purposes, respectively. Ammonium-N concentrations below 0.5 mg L^{-1} are recommended for potable human purposes, while concentrations above 2.5 mg L^{-1} may be harmful to fish (USEPA, 1973). In the case of P, SP concentrations above 0.01 mg L^{-1} and TP concentrations above 0.02 mg L^{-1} have been suggested as levels that, if exceeded, may accelerate the eutrophication of impoundments and lakes (USEPA, 1984; Vollenweider and Kerekes, 1980).

Mean NO_3-N (<0.7 mg L^{-1}) and NH_4-N (<0.12 mg L^{-1}) concentrations are well within recommended limits, and pose no cause for concern. However, mean concentrations of both SP (0.16 and 0.19 mg L^{-1}) and TP (3.8 and 7.6 mg L^{-1}) in runoff exceeded the critical levels, by more than an order of magnitude. Actually, the relatively high concentrations of TP, and also TKN, are not surprising in view of the large amounts of sediment discharged (Table 1). With regard to the other parameters, neither pH nor conductivity posed a water quality or a plant growth concern.

Mean annual amounts of nutrients in surface water runoff are of interest from both environmental and agronomic standpoints. Besides providing information on potential nutrient loading to water bodies, the values provide soil fertility/conservation insights. Overall, mean soluble losses for the peanut watersheds were < 0.9, < 0.1 and < 0.3 kg ha^{-1} yr^{-1} for NO_3-N, NH_4-N, and SP, respectively. Comparable amounts received from rainfall in the area are about 3, 3, and 0.06 kg ha^{-1} yr^{-1} (Sharpley *et al.*, 1991). Consequently, net losses of the soluble nutrients in surface water runoff from the peanut watersheds were small, and often were approached or exceeded by rainfall contributions. On the other hand, particulate nutrient losses were relatively high, ranging from 4 kg ha^{-1} for P to 20 kg ha^{-1} for N, again, reflecting the high sediment discharge from the watersheds.

Prediction of Nutrient Discharge in Surface Runoff

Accurate prediction of nutrient discharge in surface water runoff is a fundamental requirement for environmental water quality models. The peanut watersheds were of particular interest in applying a predictive approach because considerable surface discharge occurred. For soluble chemicals, a recently developed, uniform-mixing, kinetic-desorption equation (Sharpley *et al.*, 1988) has been proposed to predict losses in surface runoff. The equation for SP may be written as

$$P_r = K\,P_A\,E\,B\,t^a\,W^{\beta}/V \qquad [1]$$

where P_r = storm average SP concentration of runoff (mg L^{-1}), K, a, and β are constants for a given soil, P_A = soil available P content (mg kg^{-1}), E = effective depth of interaction between surface soil and runoff in SP transport (mm), B =

Table 3. Flow-weighted, mean annual and range of chemical characteristics of surface water runoff from peanut watersheds.

Watershed	NO_3-N		NH_4-N		TKN		SP		TP		Conductivity		pH	
	Mean	Range	Mean	Range	Mean	Range	Mean	Range	Mean	Range	Mean	Range	Mean	Range
	CONCENTRATIONS													
	(mgL^{-1})										(µmhos cm^{-1})			
FC-1	0.64	0.44-0.80	0.06	0.05-0.07	12	9-15	0.16	0.13-0.23	3.80	2.70-5.13	44	38-51	7.2	6.8-7.5
FC-2	0.66	0.34-1.87	0.11	0.05-0.13	25	5-41	0.19	0.07-0.37	7.57	1.42-14.48	109	45-394	6.7	6.4-7.7
	AMOUNTS													
	(kg ha^{-1})													
FC-1	0.84	0.43-1.45	0.08	0.05-0.10	15	9-18	0.19	0.14-0.22	4.4	3.1-5.2	-		-	
FC-2	0.37	0.06-0.79	0.09	0.0-0.17	20	1-48	0.29	0.01-0.91	5.9	1.0-10.8	-		-	

soil bulk density (Mg m^{-3}), t = storm duration (min.), W = water:soil ratio (cm^3 g^{-1}), and V = total runoff (mm) during the event. Because the equation incorporates parameters describing depth of surface soil-runoff interaction, storm size, and runoff water/suspended soil ratio, it is more versatile than conventional transport equations involving partition coefficients or equilibrium relations (Sharpley and Smith, 1989).

In the case of soluble N, no desorption equation was employed, because the primary constituent, nitrate, is not generally sorbed by soil material. Nitrate in soil tends to move down the profile with the initial infiltrating rain, away from the zone of surface runoff.

Sediment associated nutrients, particulate N (PN) and particulate P (PP), in surface runoff were predicted using an enrichment ratio (ER) approach (Sharpley *et al.*, 1988) where

$$\text{PN} = \text{Soil TKN} \cdot \text{Sediment concentration} \cdot \text{NER} \quad [2]$$

$$\text{PP} = \text{Soil TP} \cdot \text{Sediment concentration} \cdot \text{PER} \quad [3]$$

where soil TKN and TP have units of mg kg^{-1}, and sediment concentration of g L^{-1} and enrichment ratios according to the referenced publication.

Results using the predictive equations for SP, PP, and PN are presented in Figure 1. In each case, the measured values were assumed correct, and all source of error was attributed to the predicted values. Values are presented on an event basis, and realistic predictions were obtained in each case, with r^2 values exceeding 0.9 and standard errors less than 22%. Therefore, the predictive approaches applied to peanut culture gave realistic values under conditions where large quantities of discharge were involved.

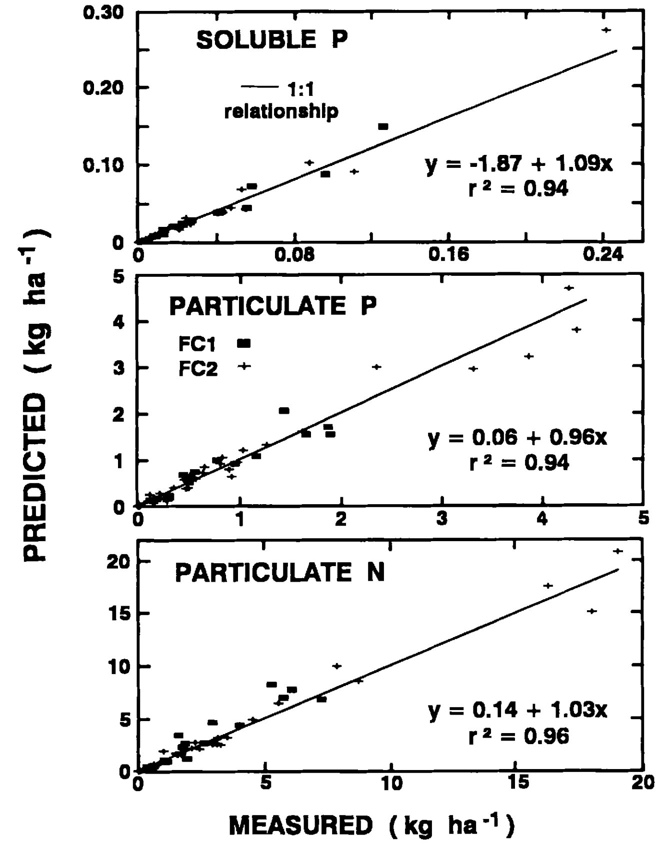

Figure 1. Comparison of predicted and measured P and N yields in surface water runoff on an event basis for the peanut watersheds.

Nutrient Concentrations in Ground Water

Table 4 contains results for soluble N (NO_3 and NH_4), P, conductivity and pH of wells on the peanut watersheds. In general, the results indicate no particular problems associated with ground water quality, and are comparable to those for the deeper ground water used for irrigation. Moreover, soluble N and P concentrations are similar to those observed for grassland and other cropland watershed wells of the area (Smith *et al.*, 1991, 1992). Even so, well water from FC-2 exhibited a maximum NO_3-N concentration slightly above the 10 mg N L^{-1} recommended limit. Therefore, some question existed as to whether nitrate "bands" were below the root zone enroute to the water table. To address this question, soil samples were taken on both watersheds down to the 3 m depth and analyzed for nitrate, and also ammonium. No evidence of a nitrate band existed, but relatively high contents of ammonium were found (i.e. up to 8 mg N kg^{-1} soil at the 2 m depth). This was unexpected because downward movement of the positively charged ammonium ion is retarded by its attachment to the negatively charged soil particles. Nevertheless, retardation may have been hampered here by the coarse texture and low sorption capacity of the subsoil. As a precautionary measure, we plan a continued monitoring of the soil profile and groundwater for both ammonium and nitrate. If deemed necessary, a possible corrective measure might be to grow a deep-rooted "scavenger" crop, such as alfalfa, to deplete the subsoil of ammonium and nitrate (Mathers *et al.*, 1975).

Pesticides

Various pesticides at the recommended rates and procedures have been applied to the watersheds through the years. Both ground water and surface runoff have been analyzed for their pesticide content. Samples were taken

Table 4. Nutrient concentrations in watershed wells.

Watershed	Period	NO_3^--N		NH_4^+-N		Soluble P		Conductivity		pH	
		Mean	Range	Mean	Range	Mean	Range	Mean	Range	Mean	Range
		mgL^{-1}						µmhos cm^{-1}			
FC-1	1983-92	2.2	0.3-4.3	0.05	0-0.2	0.07	0.01-0.10	427	360-501	7.8	6.9-8.5
FC-2	1983-92	5.8	0-13.1	0.04	0-0.2	0.04	0.02-0.06	345	301-404	8.1	6.7-8.5

during the middle (1984) and end (1991) of the study period. Analyses have included organo chlorine (0.001 $\mu g L^{-1}$ detection limit), organo phosphate (0.01 $\mu g L^{-1}$ detection limit), phenoxy (0.01 $\mu g L^{-1}$ detection limit), Bravo (0.01 $\mu g L^{-1}$ detection limit), Dual (10 $\mu g L^{-1}$ detection limit), Furadan (0.5 $\mu g L^{-1}$ detection limit), Lorsban (0.01 $\mu g L^{-1}$ detection limit) and Vernam (0.1 $\mu g L^{-1}$ detection limit). In each case, pesticide residue concentrations were below limits of analytical detection. Therefore, even though the data are limited, to date neither surface nor ground water quality problems associated with pesticide usage on the peanut watersheds have been encountered. We emphasize, however, that our sampling represents a simple, general survey at two arbitrary periods, which were not timed to coincide with recent application of any particular pesticide.

Summary and Conclusions

Water quality results for the peanut watersheds indicate soluble N (i.e. nitrate and ammonium) concentrations in surface runoff were well within recommended guidelines. In the case of P, both SP and TP exceeded somewhat the proposed 0.01 and 0.02 mg L^{-1} respective initial levels for eutrophication. This has been shown to be the case, also, for baseline, unfertilized native grasslands of the area (Smith *et al.*, 1992), indicating the general impracticability of attempting to achieve such stringent P criteria in surface waters.

Successful prediction of SP, TN and TP in surface water runoff using appropriate kinetic desorption and enrichment ratio equations indicated the approaches have realistic applicability under conditions involving high sediment discharge.

With regard to groundwater quality, N and P concentrations were found to pose no particular water quality problems, and were similar to data observed for other croplands and grasslands in the area (Smith *et al.*, 1991, 1992). However, some higher soil concentrations of ammonium (up to 8 mg N kg^{-1}) were detected below the normal rooting zone, with potential to move toward the water table. Current plans are to monitor soil profiles periodically to determine whether future corrective action (i.e., planting a deep-rooted N scavenging crop) may be warranted.

Surface runoff and ground waters were sampled for pertinent pesticides during the middle and end of the study period. Therefore, only limited pesticide information was available. In no case, however, were detectable pesticide concentrations observed.

Annual sediment discharge from the two peanut watersheds approximated 20,000 kg ha^{-1}, compared to the recommended tolerance soil loss "T" value of 4400 kg ha^{-1} for Cobb fine sandy loam (Soil Conservation Service, 1979). Consequently, from both an environmental and agronomic standpoint, additional attention should be directed to reducing soil erosion. This can be done by more judicious use of cover crops (Sharpley and Smith, 1991), and/or employment of reduced tillage cultural practices.

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