Relationship of Soil Moisture with the Incidence of Pod Rot in Peanut in West Texas[1]

V. Choppakatla*, T.A. Wheeler[2], G.L. Schuster[3], C. Robinson[3], and D.O. Porter[4]

ABSTRACT

Pod rot is a problem on peanut in West Texas and many other areas. Crop consultants scouting fields assume that pod rot will be more severe in high moisture areas of the field, and therefore bias the intensity of their sampling to those areas. The objective of this research was to evaluate the relationship between soil moisture and pod rot incidence in irrigated fields. Studies were conducted in four fields located in Yoakum County, TX in 2002 and 2003. Surface soil moisture (0 to 12 cm in depth) was measured at 5 min and 24 hr after the center pivot irrigation system passed from each sampling point (20 to 34 points/field). Three plant samples were collected at each point in August and October, and were evaluated for pod incidence. In one field where *Pythium* spp., but not *Rhizoctonia* spp. was isolated from rotted pods, pod rot incidence in August was negatively correlated with soil moisture at 5 min ($r = -0.41$, $P = 0.04$, $n = 25$) and 24 hr ($r = -0.43$, $P = 0.03$, $n = 25$). No correlations between disease and soil moisture in the other three fields was found. Results from these studies suggest that pod rot associated with *Pythium* spp., or *Pythium* spp. and *Rhizoctonia* spp., is not greater in wetter areas of irrigated peanut fields. A comprehensive approach to sampling, irrespective of soil moisture content, is essential for accurate estimation of pod rot.

Key Words: Pythium, Rhizoctonia.

Peanut is an important cash crop in Texas with production estimated at 0.4 million metric tons during 2005 and an average statewide yield at 3,850 kg/ha (Texas Agricultural Statistics Annual Bulletin, 2005). Peanut production is concentrated in the Southern High Plains of Texas (West Texas), which contributes about 70% of the state's total yield (Texas Agricultural Statistics Annual Bulletin, 2005).

Pod rot is an important disease problem on peanuts in West Texas (Wheeler *et al.*, 2006). The disease is widespread among the peanut growing areas of the world with yield losses ranging from 5–50% (Frank, 1968; Kolte, 1984; Mercer, 1977). In the United States, pod rot is a problem in peanut growing states such as North Carolina, Oklahoma, Virginia and Texas (Filonow *et al*, 1985; Garren, 1964a; Hollowell *et al.*, 1998; Wheeler *et al.*, 2006). As early as in 1961, substantial losses in yield and market quality of peanuts due to pod rot was reported in Virginia (Garren, 1964a). In Oklahoma. 43% of 37 peanut fields sampled during the early 1980's had pod rot with the disease incidence ranging from 5–36.7% (Filonow *et al.*, 1985). In North Carolina, a farm survey estimated mean incidence of pod rot at 6.6% in 1995 and 5.9% in 1996 (Hollowell *et al.*,1998). Most recently, pod rot was reported in 58% of the 107 sampled peanut fields in Texas Southern High Plains (Wheeler *et al.*, 2006).

Various biotic and abiotic factors are involved in incidence and severity of pod rot. Species of *Pythium* and *Rhizoctonia* are often the most important causal organisms of pod rot (Frank, 1968; Garren, 1963; Hollowell *et al.*, 1998; Wheeler *et al.*, 2006). Other fungi isolated from diseased pods include *Aspergillus* spp., *Cylindrocladium parasiticum*, *Fusarium* spp., *Macrophomina phaseoli*, *Rhizopus* spp., *Sclerotinia minor* and *Sclerotium rolfsii* (Csinos *et al.*, 1984; Hollowell *et al.*, 1998; Mercer, 1977; Porter *et al.*, 1982). Soilborne mites and plant parasitic nematodes were also been reported to play a significant role in pod rot incidence (Garcia and Mitchell, 1975; Shew and Beute, 1979). However, plant pathogens may not always be the primary cause of pod rot. Nutrient imbalance such as deficiency of calcium and excess of other competitive cations in the pods was shown to predispose the pods to pathogen infection (Csinos *et al.*, 1984). Many studies have underlined the importance of calcium in controlling pod rot (Csinos and Gaines, 1986; Garren, 1964; Hallock and Garren,1968). However, arguments to the positive effects of calcium in controlling pod rot were also found (Filonow *et al*, 1988).

Resistance to *Pythium* pod rot has been reported in some peanut genotypes (Frank and Krikun,

[1]This research was supported by the Texas State Precision Agriculture Initiative, Western Peanut Growers Association, Texas Agricultural Experiment Station, and West Texas A&M University.

[2]Texas Agricultural Experiment Station, Lubbock, TX 79403.

[3]Division of Agriculture, WTAMU, Canyon, TX 79016.

[4]Texas Cooperative Extension, Lubbock, TX 79403.

*Corresponding author: V. Choppakatla (email: VijayC@BioSafeSystems.com).

1969; Garren, 1970; Godoy *et al*, 1984; Godoy *et al*., 1985; Smith *et al*., 1989). However, most of the current high oleic runner market types that comprise the largest percentage of acreage in West Texas are susceptible to *Pythium* pod rot infection (Texas Peanut Production Guide, 2001). Even though cultivars such as Tamrun 96 and Tamspan 90 have some resistance to *Pythium* pod rot, they are not widely cultivated in West Texas ((Texas Peanut Production Guide, 2001). Application of a calcium source such as gypsum at pegging may be helpful for pod rot control. However, West Texas soils are usually high in calcium and any additional application in the form of gypsum to control pod rot can be expensive for the grower due to high transportation costs (Texas Peanut Production Guide, 2001). Fungicides used to control pod rot (azoxystrobin, mefenoxam, flutolanil) are applied approximately 50–70 d after planting when pegs or young pods are present. While leaf spot control recommendations are to apply fungicides on a 10–14 d interval, pod rot applications are more typically 30 d apart. In West Texas, disease occurs from mid-July through September and the crop is dug in late September and through October. According to the fungicide label, two fungicide applications provide less than 60 d of protection. However, the susceptible period lasts for at least 75 d if counting from the onset of pegging (Texas Peanut Production Guide, 2001). Protection during the entire period when pegs or pods are present requires at least three fungicide applications, thereby significantly increasing production costs. A major percentage of peanut acreage is scouted for disease in West Texas and the advice of a scout is a key factor in making a decision on control including use of a fungicide (Smith *et al*., 1998). Hence, many producers prefer to use scouts to recommend the timing of the applications, rather than spray by a calendar date. At $20/ha in Terry and Yoakum counties (pers. comm. Texas Pest Management Association), the cost of a crop consultant in this region is considerably less than a fungicide application for pod rot control. Consultants prefer to delay the first fungicide spray as long as possible and save an application for late August or early September when the risk of pod rot incidence is greatest.

Irrigation is important for profitable peanut production in West Texas, where average annual rainfall is < 51 cm and rainfall from June through August is < 19 cm. In West Texas, 61 to 71 cm of water is needed per growing season for optimum peanut yield and the months of highest water demand are June, July, and August (Texas Peanut Production Guide, 2001). However, irrigation can increase the development of diseases by its influence on moisture and temperature (Frank and Ashri, 1985; Frank, 1967; Porter *et al*., 1987). Seedling diseases caused by *Pythium* spp. and *Rhizoctonia solani* are more severe under cool, wet conditions (Bateman, 1961; Klisiwicz, 1968; Mendel *et al*., 1995; Wright, 1957). In irrigated peanuts, diseases such as pod rot are influenced by various factors which include structural make up of pods (Godoy *et al*., 1985; Pettit *et al*., 1975); the complex of pathogens present including multiple species of *Pythium* and *Rhizoctonia solani* (Garcia and Mitchell, 1975; Hollowell *et al*., 1998; Wheeler *et al*., 2006); and the effect of fungicides that may target only part of the pathogen complex, and do not eradicate the problem (Texas Peanut Production Guide, 2001). The logical view that wetter soil equals more disease may not be an adequate hypothesis while making recommendations for controlling the disease on irrigated peanuts.

The purpose of this study was to evaluate whether there was a consistent and positive association of pod rot incidence caused by *Pythium* spp. alone or in association with *Rhizoctonia* spp., with soil moisture in irrigated peanut fields in an environment where water is not significantly limiting infection or plant growth.

Materials and Methods

Studies were conducted in four commercial fields in Yoakum County, TX during 2002 and 2003 (Table 1). The producer practiced a four-year rotation program with wheat -watermelon-wheat-peanut. Fields were selected that had a history of pod rot in previous peanut crops. In addition, a general survey of these fields ascertained the presence of pod rot. In each year, the fields chosen were a Brownfield (Loamy, mixed, superactive, thermic Arenic Aridic Paleustalfs) fine sand or Amarillo (Fine-loamy, mixed, superactive, thermic Aridic Paleustalfs) loamy fine sand, (Table 1). The Brownfield type soils had a higher sand content and lower clay content than the Amarillo type soils. One of the four fields (field 22) appeared to have greater slope compared to other three fields. Soil analysis report from fields 22 and 32 indicated high concentrations of nutrients including calcium (Table 2). The soil pH was near neutral and organic matter content was very low (Table 2). All fields had approximately 25 ha planted to AT1-1, a runner type peanut and 25 ha that was planted to wheat in the fall and fallowed the following summer. The fields were irrigated by center-pivot, sprinkler irrigation systems.

Table 1. Attributes of commercial peanut fields where the relationship between soil moisture and pod rot was studied.

Field	Year	Soil series	Cultivar	Planting date	Fungicide Name	Application date	Rate
							g ai/ha
22	2002	Brownfield fine sand	AT1-1	5 May 2002	Azoxystrobin	15 Jul.	249
					Tebuconazole	6 Sep.	200
32	2002	Amarillo loamy fine sand	AT1-1	4 May 2002	Azoxystrobin	24 Jun.	249
					Flutolanil	23 Jul.	694
					Mefenoxam	23 Jul.	286
					Mefenoxam	21 Aug.	203
					Chlorothalonil	2 Sep.	1228
40	2003	Brownfield fine sand	AT1-1	26 Apr. 2003	Flutolanil	3 Jul.	741
					Mefenoxam	3 Jul.	295
					Flutolanil	9 Aug.	741
					Mefenoxam	9 Aug.	295
42	2003	Amarillo loamy fine sand	AT1-1	28 Apr. 2003	Flutolanil	1 Jul.	741
					Mefenoxam	1 Jul.	295
					Mefenoxam	3 Aug.	295

Fungicide applications of mefenoxam (Ridomil Gold EC; Syngenta Crop Protection, Greensboro, NC) were applied by the producer to fields 32, 40, and 42 for *Pythium* pod rot (Table 1). Field 22, which had a *Pythium* incited early-season peg rot was treated with azoxystrobin (Abound FL; Syngenta Crop Protection, Greensboro, NC) (Table 1). All four fields were treated with either azoxystrobin (Abound FL; Syngenta Crop Protection, Greensboro, NC) or flutolanil (Moncut 70 DF; Gowan Company, Yuma, AZ) or both to control *Rhizoctonia* pod rot (Table 1).

Moisture readings were taken by following the sprinkler, rather than independent of the sprinkler position, since rainfall totals for July and August 2002 and 2003 were low. Soil moisture was measured in August using a theta probe (Model: ML2x, Delta-T Devices Ltd., Cambridge, UK) at 5 min and 24 hr after irrigating particular areas in the field. Theta probe uses a simplified impedance measuring system to determine the soil water content (Gaskin and Miller, 1996). The device consists of an oscillator, fixed impedance section of coaxial transmission line and a sensing probe whose impedance depend on the dielectric constant of the surrounding soil. An amplitude difference occurs when there is a difference in the impedance between the probe and coaxial transmission, following a signal propagation from the oscillator. Amplitude difference in turn provides the apparent dielectric constant value, which is directly proportional to the volumetric water content. The linear relationship is depicted as $\theta_v = (\sqrt{\varepsilon} - a_0)/a_1$ where, θ_v = volumetric soil water content, expressed as a ratio (m^3/m^3), ε = apparent dielectric constant and a_0 and a_1 are constants that change with soil type. The method used in the theta probe compares well with results from the standard neutron probe under simulated field conditions, confirming its acceptance in general irrigation research (Gaskin and Miller, 1996).

Soil-specific calibrations were conducted on eight undisturbed soil samples collected from each field (Fig. 1A and 1B). Theta probe measurements were taken by inserting the sensing head into the soil core sample. Soil wet weights were recorded and the sample was oven dried at 105 C for 24 hr. Gravimetric soil water content (%), dry bulk density (gms/cm^3) and volumetric soil moisture content (%) were determined (Gardner, 1986;

Table 2. Soil analysis report of commercial peanut fields.

Field	OM[a] %	Soil pH	Phosphorus P ppm	Potassium K ppm	Magnesium Mg ppm	Calcium Ca ppm	Nitrate NO3 ppm	CEC[b] meq/100 g	PBS[c] K	PBS[c] Mg	PBS[c] Ca
22	0.6	7.3	39	219	220	1081	24	7.8	7.1	23.1	68.9
32	0.8	7.2	36	269	213	1346	20	9.2	7.5	19.0	72.8

[a]Organic Matter.
[b]Cation Exchange Capacity expressed in milliequivalents per 100 g of soil.
[c]Percent Base Saturation.

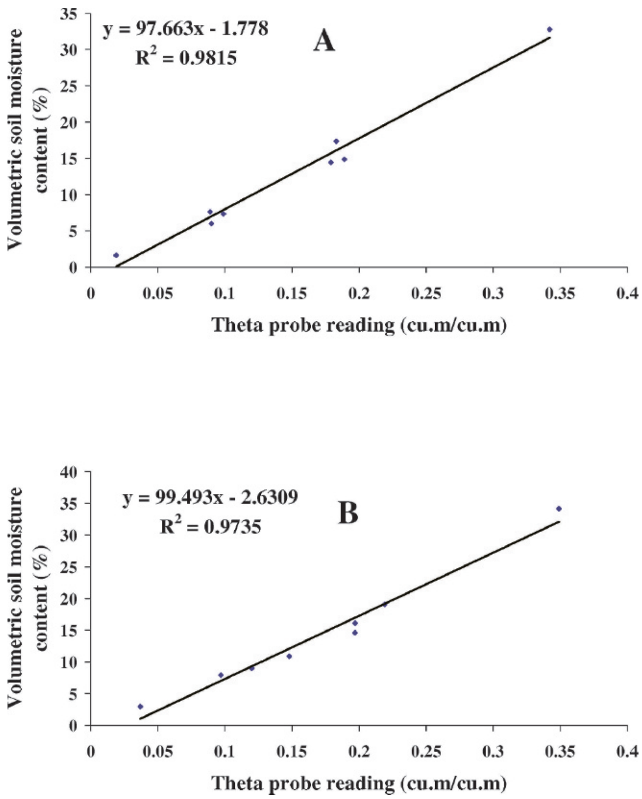

Fig. 1. Calibration of theta probe in grower field soils: (A) Amarillo loamy fine sand, (B) Brownfield fine sand.

Hartge and Blake, 1986). Estimated volumetric soil moisture content (%) was regressed against the theta probe measurements (m^3/m^3) to derive the following linear model: Volumetric soil water content (%) = $a \times$ theta probe reading (m^3/m^3) + b, where a = slope and b = intercept.

The sensing head of the theta probe was inserted into the soil such that the sensing element measured volumetric moisture content (m^3/m^3) over a 6–12 cm depth. The typical peanut fruiting depth is 6–8 cm. The difference between the moisture readings taken at 5 min and 24 hr was calculated for each field and expressed as mean percentage drainage.

The total number of sampling sites varied for each field (Table 3). Sampling points were along the line (radius) of the sprinkler irrigation system with 3–4 hr intervals, to allow the sprinkler to proceed farther around the field (Fig. 2). Gaps in the field where no data were collected occurred when peanuts were irrigated during the night hours. After the 24 hr soil moisture reading, three plant samples were collected at each moisture measuring point and percent incidence of pod rot was estimated by weighing pods with symptoms of pod rot divided by total weight of pods from three plants. An additional disease assessment was made in October at the same locations as in August.

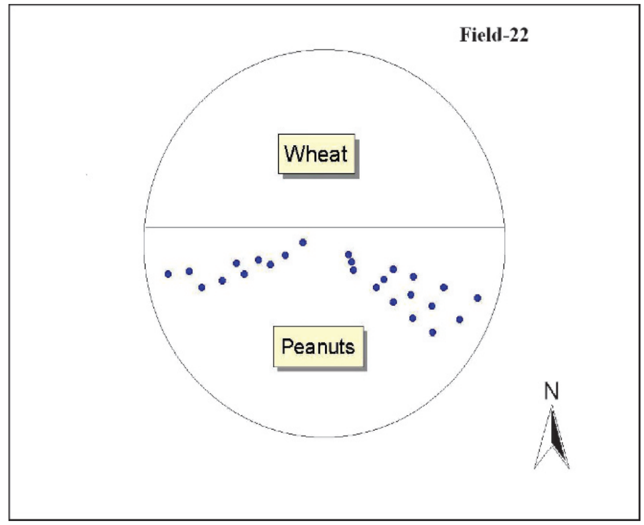

Fig. 2. Representation of data locations in field 22. A line of five points represents the position of irrigation pivot. Soil moisture and pod rot incidence was collected at each of these points. A similar strategy was followed in all of the fields.

Eight pods with characteristic symptoms of pod rot were collected at harvest from each sampling point and were assayed for the presence of fungi. Pods were washed for several minutes and then dried for 2–3 hr at room temperature. Each pod lesion was split into two pieces, one plated out on water agar and the other on a *Pythium* selective medium (Lewis and Filonow, 1990). Mycelium was transferred to potato dextrose agar to obtain pure cultures for identification. Mean percentage of total pods that were positive for either *Pythium* or *Rhizoctonia* was calculated for each sample. Product-moment correlations were calculated between the soil moisture readings and disease incidence that occurred during August and October, using the CORR procedure from SAS (SAS Institute Inc., Cary, NC).

The Yoakum County weather station within the Texas Tech-West Texas mesonet system (latitude = 33.2281, longitude = −102.8394) was used to monitor soil temperature and rainfall events. Rainfall totals would not necessarily be accurate since the station was some distance from field sites, but provides a good indication of seasonal trends.

Results

The weather in Yoakum County was dry during July and August in 2002 and 2003 and hence water applied to the peanut fields through irrigation was the primary source of moisture during this period. Immediately after irrigation, soil moisture content differences within a field were as low as 6% (field 22) to as great as 14% (field 40) (Table 3). Overall, the incidence of pod rot was higher in August

Table 3. Soil moisture and pod rot incidence in commercial peanut fields.

		Soil moisture					Pod rot range[e]		Pod rot mean[f]	
		5 min[b]		24 hr[c]						
Field	N[a]	Range	Mean	Range	Mean	%D[d]	Aug[g]	Oct[h]	Aug	Oct
22	25	21–27	25.2±1.7[i]	10–23	17.2±3.4	32	0–27	0–18	4.4±8.2	3.9±5.1
32	25	19–29	26.7±2.0	12–24	19.1±3.0	27	0–23	0–36	4.9±5.7	8.0±8.8
40	27	17–31	24.5±3.6	12–26	18.5±3.4	25	0–64	0–7	5.2±12.4	1.8±2.1
42	34	19–32	27.0±3.2	14–26	21.0±2.8	23	0–37	0–13	6.1±9.0	2.0±3.4

[a]Number of observations.
[b]Range and mean of % volumetric soil water at 5 min after irrigation.
[c]Range and mean of % volumetric soil water at 24 hr after irrigation.
[d]Mean % drainage = $(M_{0.08} - M_{24}) \times 100 / (M_{0.08})$.
[e]Range of pod rot incidence in %, measured in August and October.
[f]Average pod rot incidence in %, measured in August and October.
[g]Month of August.
[h]Month of October.
[i]Standard deviation.

compared to the end of the growing season except in field 32, where increased disease incidence was observed at harvest (Table 3).

Pod rot incidence in August was negatively correlated with soil moisture at 5 min (r = −0.41, P = 0.04, n = 25) and 24 hr (r = −0.43, P = 0.03, n = 25) in field 22 (Table 3). For the same field, pod rot incidence in October was not significantly correlated with soil moisture readings (Table 4). This field had substantial topographical changes, and the highest incidence of pod rot was found on the steepest slope of a hill, rather than in the low area of the field. No significant correlations were found between pod rot incidence and soil moisture in other fields (Table 4).

Infected pods showed symptoms of either black watery rot or brown decay and seeds inside severely rotted pods were completely decayed. In all four fields, *Pythium* spp. was the most common pathogen isolated from rotted pods, followed by *Rhizoctonia* spp. In fields 22 and 32, only *Pythium* spp. were found whereas both *Pythium* spp. and *Rhizoctonia solani* were found in fields 40 and 42 (Table 5). *Sclerotium rolfsii* was isolated from two sampling points in field 22 (Data not presented).

Discussion

The negative correlation between soil moisture and pod rot incidence observed in field 22 is contrary to that predicted by controlled experiments on the effect of *Pythium* spp. and soil matric potential, where the severity of infection was greater under wet soil conditions (Bhatti and Kraft, 1992; Hering *et al*., 1987; Pankhurst *et al*., 1995; Pieczarka and Abawi, 1978; Stanghellini *et al*., 1983). High soil moisture content favors the development of oospores and prevented the formation of sporangia by *Pythium ultimum* (Bainbridge, 1970). However, it is important to note that soil moisture and temperature optimal for infection can vary among different species of *Pythium*

Table 4. Product-moment correlations of pod rot incidence with soil moisture collected from four commercial peanut fields during 2002–03[a].

	Field number							
	22		32		40		42	
Sampling date[b]	5 min[c]	24 hr[d]	5 min	24 hr	5 min	24 hr	5 min	24 hr
August	−0.41	−0.43	0.16	0.12	0.00	0.08	−0.12	−0.06
	(0.04)	(0.03)	(0.46)	(0.56)	(1.00)	(0.67)	(0.50)	(0.72)
October	−0.32	−0.29	0.05	−0.01	−0.12	0.16	0.19	0.14
	(0.12)	(0.16)	(0.80)	(0.95)	(0.54)	(0.42)	(0.28)	(0.42)

[a]Significance level is denoted in parentheses.
[b]Pod rot incidence measured in August and October.
[c]Soil moisture read 5 min after irrigation.
[d]Soil moisture read 24 hr after irrigation.

Table 5. Recovery of *Pythium* spp. and *Rhizoctonia* from rotted pods collected from commercial peanut fields[a].

Field	N[a]	Percentage of pods[b]	
		Pythium spp	*Rhizoctonia solani*
22	200	6	0
32	200	11	0
40	216	15	4
42	272	8	6

[a]Total pods assayed. At harvest, 8 pods with pod rot symptoms were assayed from all three plantsamples collected from each moisture measuring point.

[b]Percentage of total pods that were positive for either *Pythium* or *Rhizoctonia*.

(Biesbrock and Hendrix, 1970). Root necrosis of peach caused by *P. vexans* was severe at periodically saturated soil water regimes, but that *P. irregulare* was unaffected by soil water conditions (Biesbrock and Hendrix, 1970). Klisiwicz (1968) found that seedling disease of sunflower caused by *Pythium ultimum* and *P. irregulare* was worse at cool temperatures, but that *P. aphanidermatum* was more damaging at higher temperatures. *Pythium myriotylum* is also more of a warm temperature species (Gay, 1969). A recent survey has shown that *Pythium myriotylum*, *P. ultimum*, and *P. irregulare* were the most common species isolated from peanut pods in West Texas (Wheeler *et al*., 2006). However, field 22, which had such an unusual relationship between soil moisture and disease, had an unknown species of *Pythium*. Isolates were collected and tested from this field on two occasions for species identification, but no sexual structures formed.

Soil moisture was measured at two intervals (5 min and 24 hr after irrigation) to assess the drainage condition of the fields. Soil moisture immediately after irrigation is subject to loss by gravitational forces and moisture retention is heavily dependent on soil texture, nature of the soil horizonation, recency of irrigation event, and landscape differences (Cassel and Nielsen, 1986). Field elevation changes, irrigation nozzle spacing, nozzle types, and proximity to the center pivot of the irrigation system may also affect the quantity of water reaching an area of the field (Kranz, 1988). The percentage drainage was relatively high in field 22 compared to the other three fields. Field 22 had obvious slopes and low-lying areas that were not seen in other fields, which could have resulted in a high runoff rate, surface movement of applied water within the field and reduced infiltration.

Even though *Pythium* spp. were isolated more frequently than *Rhizoctonia* in all the fields, the overall percentage of positive isolations was low. It is not known whether fungicide applications made during the season for pod rot control or soil factors such as pH have affected the mean percent recovery of *Pythium* spp. and *Rhizoctonia* spp. The frequency of *Pythium* spp. and *Rhizoctonia* spp. and the percentage of disease caused by each of these pathogens may change from year to year (Hollowell *et al*., 1998; Wheeler *et al*., 2006). Pod rot was not associated with any above ground symptoms or root infection. In all the fields except field 32, estimated pod rot incidence was higher during August compared to the estimates made near the end of the growing season. It is not known why pod rot levels were high in field 32, since it was treated both in July and August with mefenoxam (Table 1).

Pod rot was aggregated in the sampled fields. An equation developed based on mean disease incidence and variance has estimated that the number of samples required to adequately estimate pod rot (coefficient of variation=0.5) was 42, 12 and 7 when fields had 1, 5 or 10% pod rot, respectively (Wheeler *et al*., unpubl.data, 2006). Results from the current study suggest that samples taken from the wettest areas of a field were not more likely to have pod rot than samples taken from drier areas. Therefore, scouting program for pod rot should not be based on site-specific soil moisture content. Instead, scouting should be done throughout the field, without bias toward soil moisture. Inadequate sampling may result in wrong estimation of the disease. Site-specific treatment of wet areas with fungicides for management of pod rot is also not suggested. When fields are sampled with inadequate intensity, recommendations for controlling pod rot including fungicide applications should be based on other factors such as field history and plant maturity rather than based on field scouting.

Acknowledgments

We sincerely thank the Western Peanut Growers Association for funding this project; and Mr. Jerry Hartman, owner of J&A Farms, Plains, TX for his assistance throughout our study in his peanut fields.

Literature Cited

Bainbridge, A. 1970. Sporulation by *Pythium ultimum* at various soil moisture tensions. Trans. Br. Mycol. Soc. 55:485-488.

Bateman, D.F. 1961. The effect of soil moisture upon development of poinsettia root rots. Phytopathology 51:445-451.

Bhatti, M.A. and J.M. Kraft. 1992. Influence of soil moisture on root rot and wilt of chickpea. Plant Dis 76:1259-1262.

Biesbrock, J.A. and F.F. Jr. Hendrix. 1970. Influence of soil water and temperature on root necrosis of peach caused by *Pythium* spp. Phytopathology 60:880-882.

Cassel, D.K. and D.R. Nielsen. 1986. Field capacity and available water capacity. pp. 901-926. *In* Methods of Soil Analysis: Physical and Mineralogical Methods. 2nd ed. Soil Science Society of America, Inc., Madison, WI.

Csinos, A.S. and T.P. Gaines. 1986. Peanut pod rot complex: a geocarposphere nutrient imbalance. Plant Dis 70:525-529.

Csinos, A.S., T.P. Gaines, and M.E. Walker. 1984. Involvement of nutrition and fungi in the peanut pod rot complex. Plant Dis 68:61-65.

Filonow, A.B., H.A. Melouk, and M. Martin. 1985. Effect of calcium sulfate on pod rot of peanut c.v 'Early Bunch' (Abstr.) Proc. Am. Peanut Res. Educ. Soc. 17:44.

Filonow, A.B., H.A. Melouk, M. Martin, and J. Sherwood. 1988. Effect of calcium sulfate on pod rot of peanut. Plant Disease 72:589-593.

Frank, Z.R. 1967. Effect of irrigation procedure on Pythium rot of groundnut pods. Plant Dis. Rep. 51:414-416.

Frank, Z.R. 1968. Pythium pod rot of peanut. Phytopathology 58:542-543.

Frank, Z.R. and A. Ashri. 1985. Pythium pod rot reduction in peanuts, as affected by breeding for resistance and by disease level. Phytoparasitica 13:41-45.

Frank, Z.R. and J. Kirkun. 1969. Evaluation of peanut (*Arachis hypogaea*) varieties for Verticillium resistance. Plant Dis. Rep. 53:744-756.

Garcia, R. and D.J. Mitchell. 1975. Synergistic interactions of *Pythium myriotylum* with *Fusarium solani* and *Meloidogyne arenaria* in pod rot of peanut. Phytopathology 65:832-833.

Gardner, W.H. 1986. Water Content. pp. 493-544. *In* Methods of Soil Analysis: Physical and Mineralogical Methods. 2nd ed. Soil Science Society of America, Inc., Madison, WI.

Garren, K.H. 1963. Evidence of two different pathogens of peanut pod rot. Phytopathology 53:746.

Garren, K.H. 1964. Landplaster and soil rot of peanut pods in Virginia. Plant Dis. Rep. 48:707-709.

Garren, K.H. 1964a. Recent developments in research on peanut pod rot. Proc. 3rd Nat'l. Peanut Research Conf. Auburn, AL., 20-27.

Garren, K.H. 1970. *Rhizoctonia solani* vs. *Pythium myriotylum* as pathogens of peanut pod rot breakdown. Plant Dis. Rep. 54:804-843.

Gaskin, G.J. and Miller, J.D. 1996. Measurement of soil water content using a simplified impedance measuring technique. J. Agric. Eng. Res. 63:153-160.

Gay, J.D. 1969. Effects of temperature and moisture on snap bean damping off caused by three isolates of *Pythium myriotylum*. Plant Dis. Rep. 53:707-709.

Godoy, R., O.D. Smith, and T.E. Boswell. 1984. Evaluation of six peanut genotypes for pod rot resistance. Peanut Sci 11:49-52.

Godoy, R., O.D. Smith, R.A. Taber, and R.E. Pettit. 1985. Anatomical traits associated with pod rot resistance in peanut. Peanut Sci 12:77-82.

Hallock, D.L. and K.H. Garren. 1968. Pod breakdown, yield, and grade of Virginia-type peanuts as affected by Ca, Mg, and K sulfates. Agron. J. 60:253-257.

Hartge, K.H. and G.R. Blake. 1986. Bulk Density. pp. 363-375. *In* Methods of Soil Analysis: Physical and Mineralogical Methods. 2nd ed. Soil Science Society of America, Inc., Madison, WI.

Hering, T.F., R.J. Cook, and W. Tang. 1987. Infection of wheat embryos by *Pythium* species during seed germination and the influence of seed age and soil matric potential. Phytopathology 77:1104-1108.

Hollowell, J.E., B.B. Shew, M.K. Beute, and Z.G. Abad. 1998. Occurrence of pod rot pathogens in peanuts grown in North Carolina. Plant Dis 82:1345-1349.

Klisiwicz, J.M. 1968. Relation of *Pythium* spp. to root rot and damping-off of safflower. Phytopathology 58:1384-1386.

Kolte, S.J. 1984. Peanut diseases. pp. 53-56. *In* Diseases of annual edible oilseed crops, vol. 1. CRC Press, Inc., Boca Raton, FL.

Kranz, W. 1988. Flow Control Devices for Center Pivot Irrigation Systems. File G88-888-A. Cooperative Extension, University of Nebraska, Lincoln, NE.

Lewis, P.I. and A.B. Filonow. 1990. Reaction of peanut cultivars to *Pythium* pod rot and their influence on populations of *Pythium* spp. in soil. Peanut Sci 17:90-95.

Mendel, H.H., H.C. Huang, G.C. Kozub, and D.J.S. Barr. 1995. Effect of soil moisture and temperature on seedling emergence and incidence of Pythium damping-off in safflower (*Carthamus tinctorius* L.). Canad. J. Plant Sci. 75:505-509.

Mercer, P.C. 1977. A pod rot of peanuts in Malawi. Plant Dis. Rep. 61:51-55.

Pankhurst, C.E., H.J. McDonald, and B.G. Hawke. 1995. Influence of soil water matric potential on the control of Pythium root infection of wheat with metalaxyl in two contrasting soils of South Australia. Aust. J. Exp. Agric. 35:603-610.

Porter, D.M., D.H. Smith, and R. Rodriguez-Kabana. 1982. Peanut plant diseases. pp. 326-410. *In* Peanut Science and Technology, H.E. Patee and C.T. Young (eds.), American Peanut Res. and Ed. Soc., Inc, Yoakum, TX.

Porter, D.M., F.S. Wright, and N.L. Powell. 1987. Effects of sprinkler irrigation on peanut diseases in Virginia. Plant Dis 71:512-515.

Pieczarka, D.J. and G.S. Abawi. 1978. Influence of soil water potential and temperature on severity of Pythium root rot of snap beans. Phytopathology 68:766-772.

Pettit, R.E., R.A. Taber, and O.D. Smith. 1975. Structural features of peanut pods: Arachis hypogaea cultivars. Proc. Amer. Peanut Res. And Educ. Assoc. 7:91. (abstr).

Shew, H.D. and M.K. Beute. 1979. Evidence for the involvement of soilborne mites in Pythium pod rot of peanut. Phytopathology 69:204-207.

Smith, D.T., M.G. New, and J.T. Criswell. 1998. Pests, Pesticide Use & Management Practices in the Southwestern Peanut Industry. National Agricultural Pesticide Impact Assessment Program USDA/CSREES and the Southern Regional Office. Technical report 98-08, Texas A&M University, College Station, and Oklahoma State University, Stillwater.

Smith, O.D., T.E. Boswell, W.J. Grichar, and C.E. Simpson. 1989. Reaction of select peanut (*Arachis hypogaea* L.) lines to southern stem rot and *Pythium* pod rot under varied disease pressure. Peanut Sci 16:9-14.

Stanghellini, M.E., L.J. Stowell, W.C. Kronland, and P. von Bretzel. 1983. Distribution of *Pythium aphanidermatum* in rhizosphere soil and factors affecting expression of the absolute inoculum potential. Phytopathology 73:1463-1466.

Texas Agricultural Statistics Annual Bulletin-2005. Texas Agricultural Statistics Service, Austin, TX.

Texas Peanut Production Guide. 2001, pp. 23-29. Texas Cooperative Extension Fact Sheet B-1514.

Wheeler, T.A., C.R. Howell, J. Cotton, and D. Porter. 2006. *Pythium* species associated with pod rot on west Texas peanut and in vitro sensitivity of isolates to mefenoxam and azoxystrobin. Peanut Sci 30:9-13.

Wright, E. 1957. Influence of temperature and moisture on damping-off of American and Siberian elm, black locust, and desertwillow. Phytopathology 47:658-662.