Relationship of Pod Damage by Southern Corn Rootworm and Soil Drainage to Peanut Yield

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ABSTRACT

No published studies have quantified the relationship between damage to peanut (*Arachis hypogaea* L.) pods by the southern corn rootworm, *Diabrotica undecimpunctata howardi* Barber, and yield. Peanut yields have generally been found to be inconsistently related to control measures (insecticide treatments) used for southern corn rootworm. This discrepancy may be caused by the variable survival of eggs and larvae in soils with different moisture retention capacities. This study determined the relationship of pod damage and the influence of soil drainage to peanut yield. Eleven on-farm tests for management of southern corn rootworm, conducted between 1989 to 1991 and involving 48 different control measures, were compiled for analysis. All experimental fields were classified into three drainage classes: moderately well drained, somewhat poorly drained and poorly drained. Yield declined with an increase in percentage pod damage ($P < 0.05$). Percentage of mature pods damaged increased with increased area poorly drained. Stepwise regression models indicated that the inherent drainage properties of a field and proportion of pod damage observed, by themselves, can explain 45% of the variance observed in yield regardless of insecticide treatment.

Key Words: Peanut, yield, pod damage, soil drainage.

The southern corn rootworm, *Diabrotica undecimpunctata howardi* Barber (Coleoptera: Diabrotica), is the most destructive pest of peanuts, *Arachis hypogaea* L., in Virginia and North Carolina (Smith and Barfield, 1982). Three and four generations per year were reported for North Carolina and Virginia, respectively (Long and Dogger, 1955; Mallory-Boush and Alexander, 1964). It overwinters in the adult stage, with emergence occurring in early March. First generation adults emerge in late June and the second generation in mid- to late July, with soil moisture during and after egg deposition being the major factor influencing abundance (Mallory-Boush and Alexander, 1964). Feeding by larvae early in the season will decrease pod production, but late infestations will result mostly in damaged pods (Chaflant and Mitchell, 1970). Few integrated pest management strategies exist for southern corn rootworm. This is mostly due to the unique biology of immature stages, which occur in the soil, making it laborious to sample. Peanut farmers in Virginia and North Carolina typically apply one preventive insecticide treatment between mid-June and the end of July to suppress southern corn rootworm with little knowledge of actual population pressure. Previous studies in Virginia showed that 30 percent pod damage was necessary before significant reductions in yield could be detected (Herbert unpublished). No published studies have quantified this relationship. Peanut yields have generally been found to be inconsistently related to control measures (insecticide treatments) used for southern corn rootworm management (Brandenburg and Herbert, 1991). While applying soil insecticides for corn rootworm control in peanut without adequate knowledge of the potential for economic damage is unwise; this practice is also widespread in corn (Turpin *et al.*, 1972; Turpin and Maxwell, 1976; Luckman, 1978; Troost *et al.*, 1992).

This study was conducted to determine how proportion of pod damage, prior to harvest, is related to yield. Pod damage is a direct indication of southern corn rootworm abundance for the season. We also evaluated the influence of insecticide treatment and soil drainage on the relationship. Soil drainage was included to determine the influence of soil moisture because drainage affects moisture retention capacities of soils, and is indirectly related to egg and larval survival.

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Table 1. Materials, methods and timing of application used for management of southern corn rootworm.

	Materials	Rates		Methods and timing of application
		kg a.i/ha	kg product/ha	
1.	Phorate	1.12		in seed furrow at planting
2.	Phorate	1.12		in seed furrow at planting
	+ Fonofos	2.24		banded at pegging [1]
3.	Phorate	1.12		in seed furrow at planting
	+ Phorate	2.24		banded at pegging
4.	Disulfoton	1.12		in seed furrow at planting
	+ Disulfoton	2.24		banded at pegging
5.	Disulfoton	1.12		in seed furrow at planting
	+ Phorate	2.24		at pegging
6.	Disulfoton	2.24		banded at pegging
7.	Phorate	2.24		banded at pegging
8.	Chlorpyrifos	4.48		broadcast preplant
9.	Chlorpyrifos	2.24		banded at planting
10.	Fonofos	2.24		banded at planting
11.	Furadan	2.24		banded at planting
12.	Chlorpyrifos	2.24		banded at flowering[2]
13.	Chlorpyrifos	2.24		banded at pegging
14.	Furadan	2.24		banded at pegging
15.	Ethoprop	2.24		banded at pegging
16.	Chlorpyrifos	1.12		banded at pegging
17.	Chlorpyrifos	2.24		broadcast at planting
18.	Chlorpyrifos	4.48		broadcast at planting
19.	Chlorpyrifos	2.24		banded at planting
20.	Chlorpyrifos	4.48		banded at planting
21.	Chlorpyrifos	2.24		banded at planting
22.	Phorate	1.12		in seed furrow at planting
23.	Chlorpyrifos	2.24		banded at pegging
24.	Phorate	2.24		banded at pegging
25.	Ethoprop	2.24		banded at pegging
26.	EXP60166A[5]		5.7	banded at pegging
27.	EXP60166A[5]		8.5	banded at pegging
28.	EXP60166A[5]		11.4	banded at pegging
29.	EXP60166A[5]		17.0	banded at pegging
30.	Ethoprop	2.24		banded at late pegging[3]
31.	Chlorpyrifos	2.24		banded at late pegging
32.	Fonofos	2.24		banded at planting
33.	Chlorpyrifos	2.24		banded at flowering
34.	Ethoprop	2.24		banded at flowering
35.	Fonofos	2.24		banded at flowering
36.	Fonofos	2.24		banded at pegging
37.	Fonofos	2.24		banded at late pegging
38.	Chlorpyrifos	2.24		braodcast preplant
39.	Chlorpyrifos	4.48		broadcast preplant
40.	Chlorpyrifos	2.24		banded preplant[4]
41.	Chlorpyrifos	4.48		banded preplant
42.	Chlorpyrifos	6.72		banded preplant
43.	Chlorpyrifos	2.24		banded at flowering
44.	Chlorpyrifos	2.24		banded at flowering
45.	EXP60431A 1.5G[5]	0.22		banded at flowering
46.	EXP60431A 1.5G[5]	0.34		banded at flowering
47.	Ethoprop	3.36		banded at pegging
48.	Phorate	2.24		banded at pegging

[1] Applied at pegging (mid July) in a 14-inch band over the row middle, then lightly soil-incorporated with cultivator sweeps in between rows.
[2] Applied at flowering (mid June) in a 14-inch band over the row middle, then lightly soil incorporated with cultivator sweeps in between rows.
[3] Applied in early August in a 14-inch band over the row middle with no soil incorporation.
[4] Applied just before planting in a 14-inch band over row middle, then soil incorporated 7.5 to 10 cm deep with a land conditioner.
[5] Experimental product, Rhone-Poulenc Ag Co., chemical composition unavailable.

Materials and Methods

We conducted 11 field tests from 1989 to 1991 on cultivar NC 7 virginia-type peanuts managed with agronomic practices common to southeastern Virginia. Soil was prepared using full tillage with mold-board plowing, disking and land conditioning. Each test involved a range of 5 to 13 different insecticide treatments plus a control without insecticide. Treatments consisted of formulations of phorate, fonofos, chlorpyrifos, disulfoton and ethoprop applied at different times (Table 1). The treatments created varying densities of southern corn rootworm due to differences in efficacy. Each treatment was replicated four times in a randomized complete block design. All plots were 4 rows (0.92 m spacing) by 12 m long. We used the number of punctured and superficially scarified pods in 20 pods picked randomly from 5 randomly selected plants (100 pods total) per plot to determine damage in mid September (2 weeks prior to harvest). The pods were also divided into two categories, i.e., mature or immature, based on presence of visible staining in the inner hulls of mature pods. Yield was determined by harvesting the two center rows from each plot (24 m) in the first week of October.

A total of 392 observations (100 pods per observation) resulted from the 11 tests. All tests were located in one of 8 different fields. Each test was either 46 m x 61 m or 61 m x 61 m. The drainage of the soils in each test was classified and mapped using procedures by the National Cooperative Soil Survey Standards, specified by the Soil Survey Manual (Soil Survey Staff, 1951) and Soil Taxonomy (Soil Survey Staff, 1975). The soils were sampled with 6-cm diameter soil bucket augers to depths of 152 cm and morphological soil characteristics were used to determine the drainage class. Starting at the edge of each test site, one soil sample was taken at every 15-m distance in a grid pattern to cover the entire test site. This resulted in 20 and 25 sampling points for each of the 46 m x 61 m and 61 m x 61 m test sites, respectively. The proportion of soils under the drainage classes of poorly drained (water is removed so slowly that soil is wet at shallow depths periodically during the growing season or remains wet for long periods), somewhat poorly drained (water is removed slowly enough that soil is wet at a shallow depth for significant periods during the growing season) and moderately well drained (water is removed from soil somewhat slowly during some periods of the year) were then calculated for each test site based on the total 20 or 25 sampling points [i.e., number of samples in the drainage class/total number of samples taken per field] (Table 2).

Analysis. The correlation between percent mature pod damage, percent immature pod damage and percent total pod damage to yield was determined for each individual test by Pearson's Correlation (SAS, 1988). Data from all the 11 tests were pooled to determine correlation among the following variables with Pearson's correlation coefficients: insecticide treatment; proportion of soil in each drainage class, i.e., poorly drained, somewhat poorly drained and moderately well drained; % of mature pods damage by southern corn rootworm; field in which the experiment was done. Field was included in the analysis to account for all other sources of variation that can affect yield such as weed management differences among fields, rainfall patterns, etc. A regression analysis was conducted for percent mature pod damage with proportion of soil in each field classified as poorly drained. A stepwise regression was conducted with yield as the dependent variable and the following as the independent variables: insecticide treatment; proportion of soil in each drainage class (poorly drained, somewhat poorly drained and moderately well drained); percent immature pod damage; and field.

Table 2. Drainage of soils of eight fields in which studies were conducted on southern corn rootworm damage to peanuts in southeastern Virginia from 1989 to 1991.

Field no.	Proportion of soils in each drainage class[1]			Test no.
	POORD	SPOOD	MODD	
1	0.70	0.30	0.00	1
2	0.70	0.30	0.00	2
3	1.00	0.00	0.00	3
4	0.00	0.13	0.87	4
5	0.46	0.49	0.04	5, 6 & 7
6	0.76	0.24	0.00	8
7	0.18	0.78	0.04	9 & 10
8	0.91	0.09	0.04	11

[1] POORD= Poorly drained soils.
SPOOD= Somewhat poorly drained soils.
MODD= Moderately well drained soils.

Results

All significant correlations between yield and the measures of pod damage (percent immature pod damage, percent mature pod damage and percent total pod damage) were negative (Table 3). The level of correlation varied with test, with r values ranging from -0.32 to -0.62, so yield declined with an increase in any of our measurements of pod damage. Also, percent mature pod damage increased with increases in percent immature pod damage in 10 out of 11 tests, and percent mature pod damage and percent immature pod damage were correlated to percent total pod damage in all cases. Therefore, any of these measures of pod damage can be used to further study the relationship between pod damage and yield. Since mature pods is the most important category of pod contributing to yield and kernel quality, it was used for further analyses.

From Pearson's correlation of pooled data, it was clear that insecticide treatment did reduce percent mature pod damage and increase yield (Table 4). Percent mature pod damage increased with an increase in proportion of poorly drained soil, so drainage classification can be an indicator of southern corn rootworm damage potential. Proportion of somewhat poorly drained and moderately well drained soil was negatively correlated to yield. Proportion of poorly drained soil was positively related to yield. As in the correlations obtained from individual tests, over all tests there was a negative relationship ($r^2 = -0.24$) between percent mature pod damage and yield. Increases in pod damage do reduce yield. Regression analysis of percent mature pod

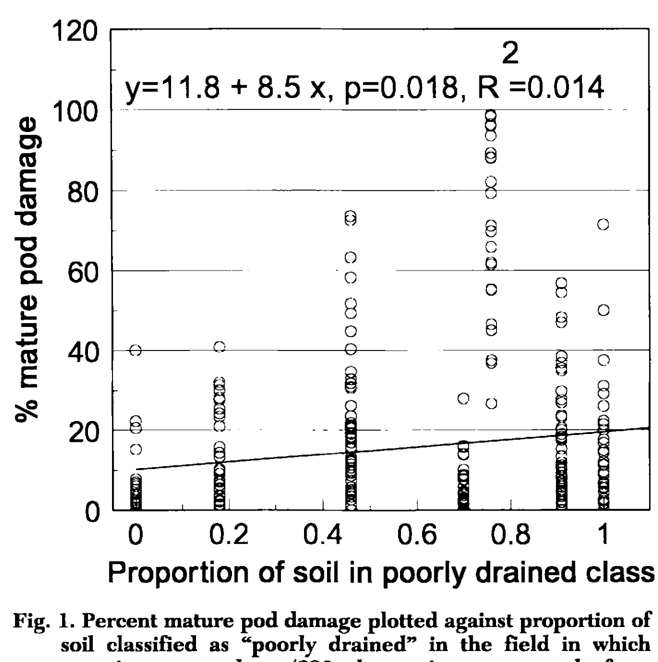

Fig. 1. Percent mature pod damage plotted against proportion of soil classified as "poorly drained" in the field in which experiment was done (392 observations were made from eight fields).

damage and proportion of soil in each field classified as poorly drained show that the relationship is linear. Although the R-square value was very low, the regression was significant ($P < 0.05$) (Fig. 1). The experiment was not designed specifically to determine this relationship; we believe this relationship can be better quantified with a different experimental design. Nevertheless, the linear relationship indicates that damage by southern corn rootworm to pods increased proportionally with an increase in proportion of poorly drained soil in a field.

Table 3. Pearson's correlation coefficient between % mature pod damage (PMD), % immature pod damage (PID), % total pod damage and yield in kg/ha (YLD) from tests on southern corn rootworm management in peanuts, conducted in southeastern Virginia from 1989 to 1991.

TEST1

Variable	PMD	PID	PTD	YLD
PMD		0.67**	0.97**	-0.34
PID			0.80**	-0.27
PTD				-0.36*

TEST 2

Variable	PMD	PID	PTD	YLD
PMD		0.77**	0.97**	0.31
PID		0.90**		0.14
PTD				0.27

TEST 3

Variable	PMD	PID	PTD	YLD
PMD		0.52**	0.81**	-0.32*
PID			0.91**	-0.50**
PTD				-0.49*

TEST 4

Variable	PMD	PID	PTD	YLD
PMD		0.59**	0.88**	-0.50*
PID			0.87**	-0.48*
PTD				-0.57*

TEST 5

Variable	PMD	PID	PTD	YLD
PMD		0.80**	0.97**	0.10
PID			0.90**	-0.03
PTD				0.06

TEST 6

Variable	PMD	PID	PTD	YLD
PMD	0.25		0.77**	-0.16
PID			0.68**	-0.18
PTD				-0.27

TEST 7

Variable	PMD	PID	PTD	YLD
PMD		0.80**	0.99**	-0.04
PID			0.87**	0.04
PTD				-0.03

TEST 8

Variable	PMD	PID	PTD	YLD
PMD	0.58*	0.98**	-0.60*	
PID			0.72**	-0.37
PTD				-0.62*

TEST 9

Variable	PMD	PID	PTD	YLD
PMD		0.83**	0.99**	-0.29
PID			0.89**	-0.29
PTD				-0.29

TEST 10

Variable	PMD	PID	PTD	YLD
PMD		0.56*	0.99**	-0.18
PID			0.64**	-0.35
PTD				-0.24

TEST 11

Variable	PMD	PID	PTD	YLD
PMD		0.64**	0.93**	0.10
PID			0.81**	0.05
PTD				0.07

*Significant at $P \leq 0.05$, **Significant at $0.001 < P < 0.05$.

The stepwise regression indicated that all six variables can affect yield (Table 5). The best 1-variable model ($r^2 = 0.02$) was obtained with insecticide treatment as the dependent variable. But, it only accounted for 2% of the variance in yield, so most of the variance in yield cannot be accounted for by insecticide treatment alone. The best 2-variable model ($r^2 = 0.04$) included insecticide treatment and field as independent variables, an indication that inherent properties of a field influence yield. The model was improved further ($r^2 = 0.06$) when drainage factor was included resulting in the best 3-variable model. When more information on drainage of the field and percent mature pod damage was included in

Table 4. Pearson's correlation coefficient between 6 variables measured from tests on southern corn rootworm damage to peanuts, conducted in southeastern Virginia from 1989 to 1991.

Variable[1]	TNT	POORD	SPOORD	MODD	PMD	FIELD	YLD	YEAR
TNT		0.05	-0.03	-0.03	-0.28**	-0.03	0.17*	0.002
POORD			-0.67**	-0.56**	0.30**	0.32**	0.30**	-0.16*
SPOORD				-0.25**	0.10	-0.81**	-0.20**	0.52**
MODD					-0.11	0.51**	-0.13**	-0.34**
PMD						0.19**	-0.24**	0.10
FIELD							-0.22**	-0.08
YLD								0.29**
YEAR								

*Significant at $P \leq 0.05$, **Significant at $0.001 < P < 0.05$.

[1] TNT= Presence/absence of insecticide treatment.
POORD= Proportion of soil in field in the drainage class "poorly drained".
SPOORD= Proportion of soil in field in the drainage class "somewhat poorly drained".
MODD= Proportion of soil in field in the drainage class "moderately well drained".
PMD= % mature pods damaged
FIELD= Field in which experiment was conducted.
YLD= Peanut yield (kg/ha).
YEAR= Year in which the experiment was conducted.

Table 5. Stepwise regression with 6 variables (TNT, POORD, SPOORD, MODD, PMD AND FIELD) to determine the best model for the dependent variable, yield of peanut (kg/ha).

		Coefficients of independent variables included by analysis in model[1]						r^2	P
	Intercept	TNT	POORD	SPOORD	MODD	PMD	FIELD		
Best 1-variable	3451.6	407.2*						0.02	0.007
Best 2-variable model	3573.8	409.5*					-34.8	0.04	0.004
Best 3-variable model	4098.7	392.7*		-772.7*			-98.0*	0.06	0.0006
Best 4-variable model	4212.0	350.0*		-816.0*		-2.9	-104.5*	0.06	0.001
Best 5-variable model	-5029.0**		62956.0**	60016.9**	65584.4*	-8.1*	-662.5*	0.45	0.0001
Best 6-variable model	-55878.5	268.1*	62494.8**	59615.4**	65113.0**	-6.3*	-653.7**	0.45	0.0001

*Signficant at $P \leq 0.05$, **Significant at $0.05 < P < 0.001$.

[1] TNT= Presence or absence of insecticide treatment.
POORD = Proportion of soil in field in the drainge class "poorly drained".
SPOORD = Proportion of soil in field in the drainage class "somewhat poorly drained".
MODD = Proportion of soil in field in the drainage class " moderately well drained'.
PMD = % mature pods damaged.
FIELD = Field in which experiment was conducted.

the model, as in the best 5-variable model (which did not included insecticide treatment), there was a large increase in the variance explained by the model (r^2 = 0.45). Inherent properties of field and pod damage, by themselves, can explain 45% of the variance in yield regardless of insecticide treatment. The 5-variable model is the best model because R-square did not improve in the 6-variable model (r^2 = 0.45) when the variable insecticide treatment was added. Over all, the stepwise regression showed that insecticide treatment generally had a positive effect on yield; effect of drainage changed with factors included in the model, indicating that there is interaction between drainage and the other factors; and percentage pod damage by southern corn rootworm always had a negative effect on yield.

Discussion

Peanut yield is affected by many factors including agronomic practices, edaphic factors, pest management practices, and others. (Pattee and Young, 1982). For example, Adams *et al.* (1993) found that the year in which the experiment was conducted, the soil series in which the peanuts were planted, the slope of the fields and surface soil texture explained 78% of the variance observed in peanut yield. In this study, we determined the effect of soil drainage, field (in which the experiment was conducted), insecticide treatment, and percent mature pod damage by southern corn rootworm on peanut yield. The best model was one (5-variable, r^2 =0.45) that included the variables, field, proportion of poorly drained, somewhat poorly drained, and moderately well drained soil, and percent mature pod damage by southern corn rootworm.

Based on the coefficient of percent mature pod damage from the best model, an 8.1 kg/ha reduction in yield is expected with every 1% increase in percent mature pod damage observed. Using the 30% pod damage level (that previous studies indicated was required for significant yield reduction) would result in a loss of approximately 240 kg/ha. Based on the selling price of $0.50 to $0.80/kg, a yield loss of 8.1 kg/ha per 1% mature pod damage, it would require 9.7% to 15.6% mature pod damage and 75.6 to 126.4 kg yield loss/ha before cost of control can be offset (Table 6). This is therefore a refinement to our earlier estimate of the relationship between pod damage by the southern corn rootworm and yield.

An economic injury level of 6.36 to 9.99 larvae per row-meter was found for the lesser corn stalkborer [*Elasmopalpus lignosellus* (Zeller)] on peanuts in a green house study. Based on a 5.87 % decrease in yield/plant per lesser cornstalk borer larva, this economic injury level resulted in a yield loss of 194kg/ha (Mack *et al.*, 1988), which would be higher than loss from the southern corn rootworm expected before cost of control is offset. Development of sound economic injury levels is a difficult task, resulting in most pesticide applications being used as preventive measures (Stern, 1973). Poston *et al.* (1983) call economic injury levels the weakest part of most management programs because economic injury levels attempt to oversimplify complex agroecosystems. But, simple calculated economic injury levels can be improvements over no- or best-guess levels (Foster *et al.*, 1986).

Table 6. Yield loss (kg/ha) and percent mature pod damage levels at which cost of control for the southern corn rootworm is offset, assuming a 8.1kg/ha loss in yield per 1% of mature pod damage and a control cost of $63/ha.

Variable	Selling price ($/kg)			
	0.50	0.60	0.70	0.80
% mature pod damage[1]	15.6	13.0	11.1	9.7
Yield loss in kg/ha[2]	126.4	105.3	89.9	75.6

[1]Control cost/(selling price x yield loss/1%mature pod damage).
[2]% mature pod damage x yield loss/1% mature pod damage.

The limited ability of damage due to corn rootworm to account for variance in yield was also observed in corn by Foster *et al.* (1986). They found that adult density and larval damage rating could account for only 5% to 16% of the variation observed in yield loss. Addition of edaphic and agronomic variables improved the models, but 60% of the variation in yield loss was still unexplained. They concluded therefore that optimal strategy for managing corn rootworms in Iowa was not to sample for adults but always to treat corn following corn with a soil insecticide at planting time.

In this study, the positive relationship between proportion of poorly drained soil with yield and negative relationship between proportion of somewhat poorly drained and moderately well drained soil with yield (Table 4) indicates that poor soil drainage not only benefited the southern corn rootworm, i.e., resulted in higher abundance, but it also benefited the peanuts, indicating that water was also a limiting factor during the three years in which the trials were done. Water deficit in peanut can delay flowering, reduce total number of flowers (Lin *et. al.*, 1963), increase the occurrence of flowers with short styles, which results in a lower rate of fertilization (Bolhuis *et al.*, 1965) and cause failure of pegs to penetrate into soil (Boote *et al.*, 1976), which results in reduced pod number and yield.

The significant relationship between soil drainage and percent mature pod damage found in this study helps to explain the poor relationship observed between southern corn rootworm adult abundance and subsequent damage to pods by larvae (Brandenburg *et al.*, 1992). In that study, no effort was made to document different edaphic factors or weather conditions and their relationship to pod damage. This study showed that soil drainage was a significant factor determining the final damage potential. This is concurrent with extensive literature on the biology of southern corn rootworm which showed that soil moisture is a key factor determining egg and larval survival (Krysan, 1976; Brust and House, 1990a, 1990b). More precise quantification of the influence of edaphic factors on damage potential by southern corn rootworm will improve our ability to make management and treatment decisions. Better knowledge should enable us to limit insecticide usage to only fields at risk to economic loss.

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