STATISTICAL STUDY OF MEASUREMENTS OF NEMATODES

by

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INTRODUCTION

1.1 Objectives

This thesis is a statistical study of data obtained from larvae of the Horsenettle and the Osborne Cyst Nematode by Dr. L. I. Miller of the Tidewater Research Station.

This study is a part of a large project being proposed by Dr. Miller, who is interested in the taxonomy of nematodes. Basically, this thesis will attempt to show appropriate techniques that should prove valuable to ascertain differences in the various measurements for the different nematode-host combinations. A discriminant function analysis will also be made to see the feasibility of classifying an unknown nematode on the basis of the several measurements. The data will be subjected to various statistical tests to see if anything can be learned that would indicate modifying the laboratory technique.

1.2 Background

The Horsenettle cyst nematode (N_1) is known to infest fields on about forty farms in Eastern Virginia where it parasitizes the horsenettle weed. In 1959, twenty-five surface soil (0-6" depth) samples of about 200 grams each were collected from all parts of a 5-acre field located two miles west of Suffolk in Nansemond County. The samples were composited and washed over a 60-mesh screen. The cysts retained on the screen were examined under a dissecting microscope and freed of trash and soil particles. The isolated cysts were washed thoroughly in sterile water to free them of other nematodes and biological contaminants. A representative aliquot of the cysts from the composite sampling was added to sterilized Ruston loamy fine sand in 6-inch clay pots which were planted to both horsenettle (p_1) and Hicks variety tobacco (p_2).

The Osborne cyst nematode (N_2) is only known to occur in one field near Scotts Fork, Virginia, in Amelia County. The infested area is confined to a 6-acre field, but this study was limited to a 3-acre tract in this field which had frequently been planted in tobacco. In 1963, soil was collected from all parts of the 3-acre tract by selecting four 6-inch deep sub-samples in 183 permanently designated plots which measured 25' X 25'. The samples were handled as described above and the pots were planted to both Horsenettle and Hicks variety tobacco.

Both of the above cultures may be referred to as mother cultures, and the nematode specimens selected for measurement were from sub-cultures of this mother culture.

Larvae selected for measurement were collected in the following manner: The soil from one sub-culture was mixed with water in a bucket and allowed to stand for about 20 seconds to permit the sand grains in the soil to settle to the bottom of the bucket. The large particles of organic trash were separated from the liquid by collection on a 35-mesh screen. The remaining liquid with the floating nematodes was passed through a 70-mesh screen to collect the cysts, through a 200-mesh screen to collect the males, and finally the larvae were collected on a 325-mesh screen. The backwash of the 200 and 325-mesh screens was placed on pieces of broadcloth held taut in an embroidery hoop. These hoops were inserted in the top of a funnel full of water and allowed to stand for 6-24 hours. The larvae and males then work their way through the cloth into the water in the funnel and free themselves of the clay and silt in which they were entrapped. The funnel contents were collected in a test tube and after about 20 minutes, the nemas settle to the bottom of the tube. The liquid at the top of the tube was then decanted off, and the nemas at the bottom of the tube were poured into a Syracuse dish. Specimens were selected at random from the dish but judgment was used in not selecting damaged specimens or specimens which were nearly dead because of starvation or old age. The specimens were mounted in a deop of isotonic salt solution in order to prevent shrinkage or swelling. Before covering the nematode in the droplet with a cover slip, it was heated very lightly over a flame to immobilize the nematode. A cover slip was then sealed on the slide with varnish and the specimen was examined microscopically.

Six measurements were made on 115 larvae from the four nematode-host combinations. The measurements are: body length, stylet length, gland oriface length, width, tail length, and tail terminal length. A schematic diagram is given in Figure 1 with the measurements indicated. The actual measurements are given in the Appendix.

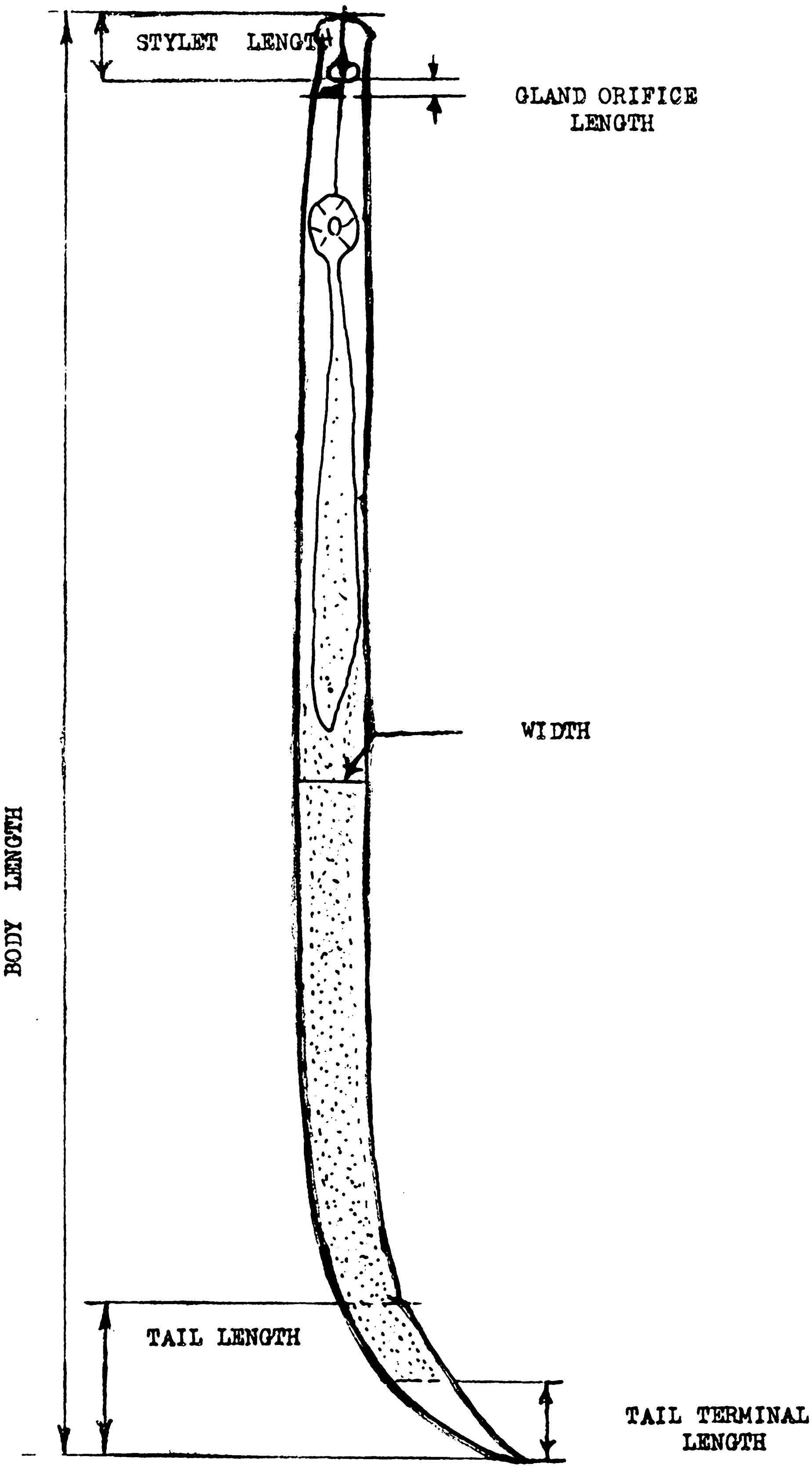

FIGURE (I) MEASUMENTS OF LARVA

II TEST OF NORMALITY

Since many of the standard statistical test and methods have been developed assuming that the observations are normally distributed, it was decided to investigate whether the nematode measurements could be considered to be normally distributed.

This chapter will be divided into three sections. In the first section, the maximum likelihood ratio test of normality will be derived; in the second section Pearson's test for goodness of fit will be described, and it will be shown to be equivalent to the maximum likelihood ratio test; and in the third section, the numerical results of Pearson's test will be given.

2.1 Maximum Likelihood Ratio Test

Let $x_1, x_2, \ldots, x_n$ be a random sample of n observations and classify these observations into k classes each with n_i observations. Let the probability of an observation falling into the i-th class be p_i where $0 \leq p_i \leq 1$ and $\sum_{i=1}^{k} p_i = 1$, then the joint density function of the random sample is

$$L(x_1, x_2, \ldots, x_n) = \frac{n!}{\prod_{i=1}^{k} n_i!} \prod_{i=1}^{k} p_i^{n_i} . \qquad (2.1.1)$$

To test the hypothesis H_0: $p_i = p_{i0}$ against H_a: $p_i \neq p_{i0}$, the maximum likelihood test procedure may be used. Let the parameter space restricted by H_0: be defined as ω, and let the unrestricted parameter space be defined as Ω.

Then

$$L(\omega) = \frac{n!}{\prod_{i=1}^{k} n_i!} \prod_{i=1}^{k} p_{i0}^{n_i} \quad . \qquad (2.1.2)$$

To get the maximum likelihood function in Ω, differentiate log(L) with respect to the p_i's subject to $\sum_{i=1}^{k} p_i = 1$.

Now

$$\text{Log}(L) = \log(n!) - \sum_{i=1}^{k} \log(n_i!) + \sum_{i=1}^{k} n_i \log p_i \ , \qquad (2.1.3)$$

and applying the restriction

$\sum_{i=1}^{k} p_i = 1$, (2.1.3) can be written as

$$\text{Log}(L) = \log(n!) - \sum_{i=1}^{k} \log(n_i!) + \sum_{i=1}^{k-1} n_i \log p_i$$

$$+ n_k \log(1 - \sum_{i=1}^{k-1} p_i). \qquad (2.1.4)$$

After setting the partial derivates equal to zero,

$$\hat{p}_i = \frac{n_i}{n} \ , \qquad (2.1.5)$$

and the maximum likelihood function in Ω is:

$$L(\hat{\Omega}) = \frac{n!}{\prod_{i=1}^{k} n_i \ (n)^n} \prod_{i=1}^{k} (n_i)^{n_i} \ . \qquad (2.1.6)$$

Since all p_{i0}'s are defined by H_0, the maximum likelihood function in ω is the same as (2.1.2), and the maximum likelihood ratio is

$$\lambda = \frac{L(\hat{\omega})}{L(\hat{\Omega})} = \prod_{i=1}^{k} \left(\frac{np_{i0}}{n_i}\right)^{n_i} . \qquad (2.1.7)$$

λ will be distributed on the interval (0,1) and H_0 will be rejected for small values of λ.

Under H_0, $-2 \log \lambda$ has asymptotically a χ^2 distribution, degrees of freedom equal to the difference between the two dimensions of Ω and ω, which equals the number of the p_i's estimated in Ω. Thus the degrees of freedom are (k-1).

In the case that a mean and variance are not specified for the normal distribution, one degree of freedom for each estimated parameter is lost. In the test of normality $-2 \log \lambda$ has asymptotically a χ^2 distribution with degrees of freedom = k-3, therefore

$$-2 \log \lambda = \sum_{i=1}^{k} n_i \log \frac{n_i}{np_{i0}} \qquad (2.1.8)$$

is distributed as a $\chi^2_{(k-3)}$.

The rejection region of H_0 contains small values of λ, which is equivalent to the large value of $\chi^2_{(k-3)}$, and as n increases, the approximation of χ^2 distribution will be improved.

2.2 Pearson's Test of Goodness of Fit

Karl Pearson [2] suggested a test for goodness of fit. This test was asymptotically equivalent to the maximum likelihood ratio test.

Pearson's test is based on the difference between the sample results of classified observations in the i-th class n_i, and the theoretical number that should be in the i-th class when H_0 is true. From the k differences, the test statistic is,

$$\lambda = \sum_{i=1}^{k} \left(\frac{n_i - n\, p_{i0}}{np_{i0}}\right)^2 , \qquad (2.2.1)$$

λ being distributed as a χ^2 with k-3 degree of freedom when both the mean and the variance are unspecified, and with k-1 degree of freedom when the two parameters are specified.

To show the equivalence of Pearson's test to the maximum likelihood test, look at the general term of the right-hand side of eq. (2.1.8) which is:

$$n_i \log \frac{n_i}{np_{i0}} = n_i \log \frac{n_i - np_{i0} + np_{i0}}{np_{i0}}$$

$$= n_i \log (1 + \Delta_i) , \qquad (2.2.2)$$

where

$$\Delta_i = \frac{n_i - np_{i0}}{np_{i0}} . \qquad (2.2.3)$$

Now (2.1.8) may be written as

$$-2 \log \lambda = \sum_{i=1}^{k} n_i \log (1 + \Delta_i), \qquad (2.2.4)$$

and from (2.2.3)

$$n_i = n\, p_{i0}(1 + \Delta_i) , \qquad (2.2.5)$$

so

$$-2 \log \lambda = \sum_{i=1}^{k} n\, p_{i0}(1 + \Delta_i) \log (1 + \Delta_i). \qquad (2.2.6)$$

When H_0 is true, and n is large, one expects Δ_i to be small, so

$$\log (1 + \Delta_i) \doteq \Delta_i \; . \qquad (2.2.7)$$

Then $-2 \log \lambda$ will be

$$\doteq \sum_{i=1}^{k} n\, p_{i0}(1 + \Delta_i)\, \Delta_i$$

$$\doteq \sum_{i=1}^{k} n\, p_{i0}\, \Delta_i + \sum_{i=1}^{k} n\, p_{i0} \Delta^2{}_i . \qquad (2.2.8)$$

Since $\sum_{i=1}^{k} n\, p_{i0}\, \Delta_i = \sum_{i=1}^{k} (n_i - n\, p_{i0}) = 0,$ (2.2.9)

$$-2 \log \lambda \doteq \sum_{i=1}^{k} n\, p_{io}\, \Delta^2{}_i$$

$$\doteq \sum_{i=1}^{k} \frac{(n_i - np_{i0})^2}{n\, p_{i0}} \quad . \qquad (2.2.10)$$

So for sufficiently large n and under H_0, $\sum_{i=1}^{k} \frac{(n_i - n\, p_{i0})^2}{n\, p_{i0}}$

is distributed as a χ^2 with (k-3) degrees of freedom.

To apply Pearson's test, classify the observations into k intervals. When the test is for normality, k should be more than three, because the degrees of freedom of the test statistic must be at least one.

The choice of intervals is arbitrary, but usually they should cover equal ranges, and the theoretical frequency for each interval should be at least one. If the theoretical frequency of the i-th interval is less than one, then:

$$(n_i - n\, p_{i0})^2 / \, n\, p_{i0}$$

will be very large, not because of a large difference between the observed frequency and the theoretical frequency, but because the theoretical frequency is small, this making a weak test.

To estimate the mean and variance of the distribution, consider that every observation that falls into the i-th interval has a value of the midpoint of the interval, m_i.

The mean of the distribution is then considered to be equal to the estimated mean

$$\bar{x} = \left(\sum_{i=1}^{k} m_i n_i\right) / \sum_{i=1}^{k} n_i$$

$$= \left(\sum_{i=1}^{k} m_i n_i\right)/n. \qquad (2.2.11)$$

The variance of the distribution is the unbiased estimator of the variance,

$$s^2 = \frac{\sum_{i=1}^{k} n_i (m_i)^2 - n(\bar{x})^2}{n-1} . \qquad (2.2.12)$$

Then the normal curve fitted to the data has the distribution

$$Y = \frac{1}{s\sqrt{2\pi}}\, e^{-\frac{1}{2}\left(\frac{x-\bar{x}}{s}\right)^2} . \qquad (2.2.13)$$

Let

$$Z_i = \frac{x_i - \bar{x}}{s} , \tag{2.2.14}$$

then the standard normal curve will be

$$f(Z) = \frac{1}{\sqrt{2\pi}} e^{-\frac{1}{2}Z^2} . \tag{2.2.15}$$

The probability p_{i0} is equal to the area under the standard normal curve which lies between Z_i and Z_{i-1}. We calculate the test statistic $-2 \log \lambda$ which is equal to

$$\sum_{i=1}^{k} \frac{(n_i - np_{i0})^2}{np_{i0}} ,$$

and compare this with the upper percentage point of a χ^2 for the required level of significance with degrees of freedom equal to k-3. Rejection means that one cannot assume normality.

The computations of the test statistic are listed systematically in Table (1).

2.3 Numerical Results

A test of normality was made for each of the measurements for each host - nematode combination. Both $\bar{x}$ and s, computed from (2.2.11) and (2.2.12) are given in each table. The χ^2-value is given at the bottom of each table and significance is indicated by an asterisk in the usual manner. The calculations were made using both the IBM 1620 and a desk calculator.

Although eight decimal places were used in the calculations, the numbers have been rounded for presentation. In the first twenty-four tables k = 4, resulting in χ^2 statistics with one degree of freedom each. The critical value for the 0.05 probability level is 3.84. From these tables it can be seen that the χ^2-statistic was significant for: (a) Stylet length for all host - nematode combinations; and (b) Gland orifice length for the Horsenettle cyst on both hosts.

The next decision involved the appropriateness of classifying the data into four intervals. Four of the sets of data, two that showed significance and two that did not, were classified into more intervals and a χ^2 calculated. From Tables 26 - 29, one can see that the same conclusions have been reached as for k = 4.

The reason for non-normality will be investigated at a later date. Any further analysis of the non-normal cases will involve non-parametric tests.

Table (1) Calculations for Test Statistic

Boundaries	m_i	n_i	Z_i	Area to the Left of Z_i	p_{i0}	np_{i0}	$\frac{(n_i - np_{io})^2}{np_{i0}}$
$x_o<x\leq x_1$	m_1	n_1	Z_1	A_1	$p_{10}=A_1$	np_{10}	$\frac{(n_1 - np_{10})^2}{np_{10}}$
$x_1<x\leq x_2$	m_2	n_2	Z_2	A_2	$p_{20}=A_2-A_1$	np_{20}	$\frac{(n_2-np_{20})^2}{np_{20}}$
-	-	-	-	-	$p_{30}=A_3-A_2$	np_{30}	-
-	-	-	-	-	-	-	-
$x_{k-1}<x\leq x_k$	m_k	n_k	Z_k	$A_{k=1}$	$p_{k0}=1-A_{k-1}$	np_{k0}	$\frac{(n_k-np_{k0})^2}{np_{k0}}$
Sum		n			1	n	$\chi^2=\sum_{i=1}^{k}\frac{(n_i-np_{i0})^2}{np_{i0}}$

Computation of Pearson's Test For

Goodness of Fit for Normality

Table (2) Body Length of Horsenettle Cyst from Horsenettle Weed

$\overline{x}$ = 505.1739 s = 28.3458

Boundaries	m_i	n_i	$\frac{x_i - \overline{x}}{s} = Z_i$	Area to the Left of Z_i	$A_i = p_{i0}$	np_{i0}	$\frac{(n_i - np_{i0})^2}{np_{i0}}$
$X \leq 480$	465	24	-0.8881	0.1873	0.1873	21.5395	0.2811
$480 < x \leq 510$	495	42	0.1703	0.5675	0.3802	43.7230	0.0679
$510 < x \leq 540$	525	35	1.2286	0.8904	0.3229	37.1335	0.1226
$540 < x$	555	14	2.2870	1.0000	0.1096	12.6040	0.1546
Sum		115			1.0000	115.0000	0.6262

$\chi^2 = 0.6262$

Table (3) Body Length of Horsenettle Cyst from Hicks Variety Tobacco

$\overline{x}$ = 512.5652 s = 26.9043

Boundaries	m_i	n_i	$\frac{x_i - \overline{x}}{s} = Z_i$	Area to the Left of Z_i	$A_i = p_{i0}$	np_{i0}	$\frac{(n_i - np_{i0})^2}{np_{i0}}$
x 490	475	25	-0.8387	0.2008	0.2008	23.0920	0.1577
490 x 520	505	46	0.2763	0.6008	0.4080	46.9200	0.0180
520 x 550	535	34	1.3914	0.9180	0.3092	35.5580	0.0683
550 x	565	10	2.5065	1.0000	0.0820	9.4300	0.0345
Sum		115			1.0000	115.0000	0.2785

$\chi^2 = 0.2785$

Table (4) Body Length of Osborne Cyst from Horsenettle Weed

$\bar{x} = 498.5652$ $s = 28.7210$

Boundaries	m_i	n_i	$\frac{x_i - \bar{x}}{s} = Z_i$	Area to the Left of Z_i	$A_i = p_{i0}$	np_{i0}	$\frac{(n_i - np_{i0})^2}{np_{i0}}$
$x \leq 470$	455	22	-0.9946	0.1600	0.1600	18.4000	0.7044
$470 < x \leq 500$	485	35	0.0500	0.5199	0.3599	41.3885	0.9861
$500 < x \leq 530$	515	42	1.0945	0.8632	0.3433	39.4795	0.1609
$530 < x$	545	16	2.1390	1.0000	0.1368	15.7320	0.0046
Sum		115			1.0000	115.0000	1.8560

$\chi^2 = 1.8560$

Table (5) Body Length of Osborne Cyst from Hicks Variety Tobacco

$\bar{x} = 508.3044$ $s = 29.2516$

Boundaries	m_i	n_i	$\frac{x_i - \bar{x}}{s} = Z_i$	Area to the Left of Z_i	$A_i = p_{i0}$	np_{i0}	$\frac{(n_i - np_{i0})^2}{np_{i0}}$
$x \leq 480$	465	23	-0.9676	0.1670	0.1670	19.2050	0.7499
$480 < x \leq 510$	495	35	0.0580	0.5227	0.3557	40.9055	0.8526
$510 < x \leq 540$	525	40	1.0836	0.8606	0.3379	38.8585	0.0335
$540 < x$	555	17	2.1091	1.0000	0.1394	16.0310	0.0586
Sum		115			1.0000	115.0000	1.6946

$\chi^2 = 1.6946$

Table (6) Stylet Length of Horsenettle Cyst from Horsenettle Weed

$\bar{x} = 24.1087$ $s = 0.8680$

Boundaries	m_i	n_i	$\frac{x_i - \bar{x}}{s} = Z_i$	Area to the Left of Z_i	$A_i = p_{i0}$	np_{i0}	$\frac{(n_i - np_{i0})^2}{np_{i0}}$
$x \leq 22.25$	21.5	3	-2.1414	0.0161	0.0161	1.8515	0.7124
$x \leq 23.75$	23.0	29	-0.4132	0.3399	0.3238	37.2370	1.8221
$x \leq 25.25$	24.5	78	1.3149	0.9055	0.5656	65.0440	2.5807
$25.25 < x$	26.0	5	3.0430	1.0000	0.0945	10.8675	3.1679
Sum		115			1.0000	115.0000	8.2831

$\chi^2 = 8.2831$*

Table (7) Stylet Length of Horsenettle Cyst from Hicks Variety Tobacco

$\bar{x} = 23.8957$ $s = 0.6265$

Boundaries	m_i	n_i	$\frac{x_i - \bar{x}}{s} = Z_i$	Area to the Left of Z_i	$A_i = p_{i0}$	np_{i0}	$\frac{(n_i - np_{i0})^2}{np_{i0}}$
$x \leq 23.5$	23	25	-0.6315	0.2640	0.2640	30.3600	0.9463
$x \leq 24.5$	24	81	0.9646	0.8325	0.5685	65.3775	3.7331
$x \leq 25.5$	25	5	2.5607	0.9949	0.1624	18.6760	10.0146
$25.5 < x$	26	4	4.1569	1.0000	0.0051	0.5865**	19.8670
Sum		115			1.0000	115.0000	34.5610

$\chi^2 = 34.5610$

**np_{40} is less than one, χ^2 is significant without $(n_4 - np_{40})^2/np_{40}$.

Table (8) Stylet Length of Osborne Cyst from Horsenettle Weed

$\bar{x} = 23.8087$ $s = 0.5758$

Boundaries	m_i	n_i	$\frac{x_i - \bar{x}}{s} = Z_i$	Area to the Left of Z_i	$A_i = p_{i0}$	np_{i0}	$\frac{(n_i - np_{i0})^2}{np_{i0}}$
$x \leq 22.5$	22	7	-2.2730	0.0115	0.0115	1.3225	24.3735
$x \leq 23.5$	23	11	-0.5362	0.2960	0.2845	32.7175	14.4158
$x \leq 24.5$	24	94	1.2007	0.8849	0.5889	67.7235	10.1952
$24.5 < x$	25	3	2.9375	1.0000	0.1151	13.2365	7.9164
Sum		115			1.0000	115.0000	56.9009

$\chi^2 = 56.9009$*

$\bar{x} = 24.1478$ $s = 0.7521$

Boundaries	m_i	n_i	$\frac{x_i - \bar{x}}{s} = Z_i$	Area to the Left of Z_i	$A_i = p_{i0}$	np_{i0}	$\frac{(n_i - np_{i0})^2}{np_{i0}}$
$x \leq 22.25$	21.5	2	-2.5233	0.0058	0.0058	0.6670**	2.6640
$x \leq 23.75$	23.0	25	-0.5289	0.3022	0.2964	34.0860	2.4220
$x \leq 25.25$	24.5	86	1.4654	0.9286	0.6264	72.0360	2.7069
$25.25 < x$	26.0	2	3.4598	1.0000	0.0714	8.2110	4.6982
Sum		115			1.0000	115.0000	12.4911

$\chi^2 = 12.4911$*

**np_{10} is less than one, but χ^2 is significant without $(n_1 - np_{10})^2/np_{10}$

Table (9) Stylet Length of Osborne Cyst from Hicks Variety Tobacco

Table (10) Gland Orifice Length of Horsenettle Cyst from Horsenettle Weed

$\bar{x} = 6.1665$ $s = 0.6026$

Boundaries	m_i	n_i	$\frac{x_i - \bar{x}}{s} = Z_i$	Area to the Left of Z_i	$A_i = p_{i0}$	np_{i0}	$\frac{(n_i - np_{i0})^2}{np_{i0}}$
$x \leq 5.5$	5.15	19	-1.1061	0.1354	0.1354	15.5710	0.7551
$x \leq 6.2$	5.85	34	0.0556	0.5020	0.3666	42.1590	1.5790
$x \leq 6.9$	6.55	53	1.2172	0.8883	0.3863	44.4245	1.6554
$6.9 < x$	7.25	9	2.3788	1.0000	0.1117	12.8455	1.1512
Sum		115			1.0000	115.0000	5.1407

$\chi^2 = 5.1407$*

Table (11) Gland Orifice Length of Horsenettle Cyst from Hicks Variety Tobacco

$\bar{x} = 6.1100$ $s = 0.7232$

Boundaries	m_i	n_i	$\frac{x_i - \bar{x}}{s} = Z_i$	Area to the Left of Z_i	$A_i = p_{i0}$	np_{i0}	$\frac{(n_i - np_{i0})^2}{np_{i0}}$
$x \leq 5.3$	4.85	17	-1.1201	0.1314	0.1314	15.1110	0.2361
$x \leq 6.2$	5.75	41	0.1245	0.5494	0.4180	48.0700	1.0398
$x \leq 7.1$	6.65	51	1.3690	0.9145	0.3651	41.9865	1.9350
$7.1 < x$	7.55	6	2.6136	1.0000	0.0855	9.8325	1.4938
Sum		115			1.0000	115.0000	4.7047

$\chi^2 = 4.7047$*

Table (12) Gland Orifice Length of Osborne Cyst from Horsenettle Weed

$\overline{x} = 5.3070$ $s = 0.5947$

Boundaries	m_i	n_i	$\frac{x_i - \overline{x}}{s} = Z_i$	Area to the Left of Z_i	$A_i = p_{i0}$	np_{i0}	$\frac{(n_i - np_{i0})^2}{np_{i0}}$
$x \leq 4.9$	4.5	29	-0.6843	0.2470	0.2470	28.4050	0.0125
$x \leq 5.7$	5.3	58	0.6609	0.7454	0.4984	57.3160	0.0082
$x \leq 6.5$	6.1	26	2.0062	0.9776	0.2322	26.7030	0.0185
$6.5 < x$	6.9	2	3.3515	1.0000	0.0224	2.5760	0.1288
Sum		115			1.0000	115.0000	0.1680

$\chi^2 = 0.1680$

Table (13) Gland Orifice length of Osborne Cyst from Hicks Variety Tobacco

$\overline{x} = 5.5852$ $s = 0.6883$

Boundaries	m_i	n_i	$\frac{x_i - \overline{x}}{s} = Z_i$	Area to the Left of Z_i	$A_i = p_{i0}$.	np_{i0}	$\frac{(n_i - np_{i0})^2}{np_{i0}}$
$x \leq 4.9$	4.5	21	-0.9956	0.1596	0.1596	18.3540	0.3815
$x \leq 5.7$	5.3	40	0.1668	0.5664	0.4068	46.7820	0.9832
$x \leq 6.5$	6.1	46	1.3291	0.9081	0.3417	39.2955	1.1439
$6.5 < x$	6.9	8	2.4914	1.0000	0.0919	10.5685	0.6242
Sum		115			1.0000	115.0000	3.1328

$\chi^2 = 3.1328$

Table (14) Width Length of Horsenettle Cyst from Horsenettle Weed

$\bar{x} = 20.5196$ $\qquad$ $s = 1.4377$

Boundaries	m_i	n_i	$\frac{x_i - \bar{x}}{s} = Z_i$	Area to the Left of Z_i	$A_i = p_{i0}$	np_{i0}	$\frac{(n_i - np_{i0})^2}{np_{i0}}$
$x \leq 19.0$	18.25	19	-1.0569	0.1455	0.1455	16.7325	0.3073
$x \leq 20.5$	19.75	37	-0.0136	0.4936	0.3481	40.0315	0.2296
$x \leq 22.0$	21.25	40	1.0297	0.8482	0.3546	40.7790	0.0149
$22.0 < x$	22.75	19	2.0730	1.0000	0.1518	17.4570	0.1364
Sum		115			1.0000	115.0000	0.6882

$\chi^2 = 0.6882$

Table (15) Width Length of Horsenettle Cyst from Hicks Variety Tobacco

$\bar{x} = 20.2326$ $\qquad$ $s = 1.4674$

Boundaries	m_i	n_i	$\frac{x_i - \bar{x}}{s} = Z_i$	Area to the Left of Z_i	$A_i = p_{i0}$	np_{i0}	$\frac{(n_i - p_{i0})^2}{np_{i0}}$
$x \leq 19.0$	18.25	26	-0.8400	0.2005	0.2005	23.0575	0.3755
$x \leq 20.5$	19.75	42	0.1822	0.5722	0.3717	42.7455	0.0130
$x \leq 22.0$	21.25	31	1.2045	0.8851	0.3129	35.9835	0.6902
$22.0 < x$	22.75	16	2.2267	1.0000	0.1149	13.2135	0.5876
Sum		115			1.0000	115.0000	1.6663

$\chi^2 = 1.6663$

Table (16) Width Length of Osborne Cyst from Horsenettle Weed

$\bar{x} = 21.6239$ $s = 1.3176$

Boundaries	m_i	n_i	$\frac{x_i - \bar{x}}{s} = Z_i$	Area to the Left of Z_i	$A_i = p_{i0}$	np_{i0}	$\frac{(n_i - np_{i0})^2}{np_{i0}}$
$x \leq 20.0$	19.25	14	-1.2325	0.1090	0.1090	12.5350	0.1712
$x \leq 21.5$	20.75	36	-0.0940	0.4624	0.3534	40.6410	0.5300
$x \leq 23.0$	22.25	49	1.0444	0.8518	0.3894	44.7810	0.3975
$23.0 < x$	23.75	16	2.1828	1.0000	0.1482	17.0430	0.0638
Sum		115			1.0000	115.0000	1.1625

$\chi^2 = 1.1625$

$x \leq 20.0$	19.25	19	-1.0981	0.1362	0.1362	15.6630	0.7110
$x \leq 21.5$	20.75	33	-0.0234	0.4906	0.3544	40.7560	1.4760
$x \leq 23.0$	22.25	47	1.0514	0.8534	0.3628	41.7220	0.6677
$23.0 < x$	23.75	16	2.1261	1.0000	0.1466	16.8590	0.0438
Sum		115			1.0000	115.0000	2.8985

$\chi^2 = 2.8985$

Table (17) Width Length of Osborne Cyst from Hicks Variety Tobacco

$\bar{x} = 21.5326$ $s = 1.3957$

Table (18) Tail Length of Horsenettle Cyst from Horsenettle Weed

$\bar{x} = 50.1696$ $s = 2.6712$

Boundaries	m_i	n_i	$\frac{x_i - \bar{x}}{s} = Z_i$	Area to the Left of Z_i	$A_i = P_{i0}$	np_{i0}	$\frac{(n_i - np_{i0})^2}{np_{i0}}$
$x \leq 47$	45.5	14	-1.1866	0.1178	0.1178	13.5470	0.0152
$x \leq 50$	48.5	40	-0.0635	0.4749	0.3571	41.0665	0.0277
$x \leq 53$	51.5	44	1.0596	0.8552	0.3803	43.7345	0.0016
$53 < x$	54.5	17	2.1827	1.0000	0.1448	16.6520	0.0073
Sum		115			1.0000	115.0000	0.0518

$\chi^2 = 0.0518$

$\bar{x} = 50.7261$ $s = 2.9973$

$x \leq 48$	46.5	25	-0.9095	0.1817	0.1817	20.8955	0.8063
$x \leq 51$	49.5	36	0.0914	0.5363	0.3546	40.7790	0.5601
$x \leq 54$	52.5	36	1.0923	0.8623	0.3260	37.4900	0.0592
$54 < x$	55.5	18	2.0932	1.0000	0.1377	15.8355	0.2959
Sum		115			1.0000	115.0000	1.7215

$\chi^2 = 1.7215$

Table (19) Tail Length of Horsenettle Cyst from Hicks Variety Tobacco

Table (20) Tail Length of Osborne Cyst from Horsenettle Weed

$\bar{x} = 50.4000$ $\qquad$ $s = 3.4661$

Boundaries	m_i	n_i	$\frac{x_i - \bar{x}}{s} = Z_i$	Area to the Left of Z_i	$A_i = p_{i0}$	np_{i0}	$\frac{(n_i - np_{i0})^2}{np_{i0}}$
$x \le 46$	44	10	-1.2694	0.1022	0.1022	11.7530	0.2615
$x \le 50$	48	45	-0.1154	0.4542	0.3520	40.4800	0.5047
$x \le 54$	52	41	1.0386	0.8503	0.3961	45.5515	0.4548
$54 < x$	56	19	2.1927	1.0000	0.1497	17.2155	0.1850
Sum		115			1.0000	115.0000	1.4060

$\chi^2 = 1.4060$

$\bar{x} = 49.9217$ $\qquad$ $s = 3.4467$

Boundaries	m_i	n_i	$\frac{x_i - \bar{x}}{s} = Z_i$	Area to the Left of Z_i	$A_i = p_{i0}$	np_{i0}	$\frac{(n_i - np_{i0})^2}{np_{i0}}$
$x \le 45$	43	11	-1.4280	0.0768	0.0768	8.8320	0.5322
$x \le 49$	47	29	-0.2674	0.3948	0.3180	36.5700	1.5670
$x \le 53$	51	55	0.8931	0.8141	0.4193	48.2195	0.9535
$53 < x$	55	20	2.0536	1.0000	0.1859	21.3785	0.0889
Sum		115			1.0000	115.0000	3.1416

$\chi^2 = 3.1416$

Table (21) Tail Length of Osborne Cyst from Hicks Variety Tobacco

Table (22) Tail Terminal Length of Horsenettle Cyst from Horsenettle Weed

$\bar{x}$ - 26.6261 s=3.5379

Boundaries	m_i	n_i	$\frac{x_i - \bar{x}}{s} = Z_i$	Area to the Left of Z_i	$A_i = P_{i0}$	np_{i0}	$\frac{(n_i - np_{i0})^2}{np_{i0}}$
$x \leq 24$	22	29	-0.7423	0.2291	0.2291	26.3465	0.2673
$x \leq 28$	26	47	0.3883	0.6510	0.4219	48.5185	0.0475
$x \leq 32$	30	31	1.5190	0.9355	0.2845	32.7175	0.0902
$32 < x$	34	8	2.6496	1.0000	0.0645	7.4175	0.0457
Sum		115			1.0000	115.0000	0.4507

$\chi^2 = 0.4507$

$\bar{x}$ = 26.1522 s = 2.9141

Boundaries	m_i	n_i	$\frac{x_i - \bar{x}}{s} = Z_i$	Area to the Left of Z_i	$A_i = P_{i0}$	np_{i0}	$\frac{(n_i - np_{i0})^2}{np_{i0}}$
$x \leq 24$	22.5	33	-0.7385	0.2301	0.2301	26.4615	1.6156
$x \leq 27$	25.5	35	0.2909	0.6144	0.3843	44.1945	1.9129
$x \leq 30$	28.5	36	1.3204	0.9066	0.2922	33.6030	0.1710
$30 < x$	31.5	11	2.3499	1.0000	0.0934	10.7410	0.0063
Sum		115			1.0000	115.0000	3.7058

$\chi^2 = 3.7058$

Table (23) Tail Terminal Length of Horsenettle Cyst from Hicks Variety Tobacco

Table (24) Tail Terminal Length of Osborne Cyst from Horsenettle Weed

$\bar{x} = 24.1261$ $s = 2.5286$

Boundaries	m_i	n_i	$\frac{x_i - \bar{x}}{s} = Z_i$	Area to the Left of Z_i	$A_i = p_{i0}$	np_{i0}	$\frac{(n_i - np_{i0})^2}{np_{i0}}$
$x \leq 22$	20.5	25	-0.8408	0.2002	0.2002	23.0230	0.1698
$x \leq 25$	23.5	47	0.3456	0.6350	0.4348	50.0020	0.1802
$x \leq 28$	26.5	37	1.5320	0.9373	0.3023	34.7645	0.1438
$28 < x$	29.5	6	2.7184	1.0000	0.0627	7.2105	0.2032
Sum		115			1.0000	115.0000	0.6970

$\chi^2 = 0.6970$

$\bar{x} = 25.2217$ $s = 3.0016$

Boundaries	m_i	n_i	$\frac{x_i - \bar{x}}{s} = Z_i$	Area to the Left of Z_i	$A_i = p_{i0}$	np_{i0}	$\frac{(n_i - np_{i0})^2}{np_{i0}}$
$x \leq 22$	20.5	20	-1.0733	0.1416	0.1416	16.2840	0.8480
$x \leq 25$	23.5	32	-0.0739	0.4705	0.3289	37.8235	0.8966
$x \leq 28$	26.5	40	0.9256	0.8227	0.3522	40.5030	0.0063
$28 < x$	29.5	23	1.9251	1.0000	0.1773	20.3895	0.3342
Sum		115			1.0000	115.0000	2.0851

$\chi^2 = 2.0851$

Table (25) Tail Terminal Length of Osborne Cyst from Hicks Variety Tobacco

Table (26) Gland Orifice Length of Horsenettle Cyst from Horsenettle Weed

$\bar{x} = 6.175$ $\qquad$ $s = 0.7682$

Boundaries	m_i	n_i	$\frac{x_i - \bar{x}}{s} = Z_i$	Area to the Left of Z_i	$A_i = p_{i0}$	np_{i0}	$\frac{(n_i - np_{i0})^2}{np_{i0}}$
$x \le 4.00$	3.625	2	-2.8313	0.00232	0.00232	0.26680**	11.2593
$x \le 4.75$	4.375	14	-1.8550	0.03180	0.02948	3.39020	0.04491
$x \le 5.50$	5.125	14	-0.8787	0.18980	0.15800	18.17000	0.95701
$x \le 6.25$	5.875	34	0.0976	0.53888	0.34908	40.14420	0.94039
$x \le 7.00$	6.625	53	1.0503	0.85858	0.31970	36.76550	7.16865
$x \le 7.75$	7.375	8	2.0503	0.97982	0.12124	13.94260	2.53285
$x \le 8.50$	8.125	1	3.0266	1.00000	0.02018	2.32070	0.75606
Sum		115			1.00000	115.00000	23.65917

$\chi^2 = 23.65917$

$\chi^2_{4(0.05)} = 9.488$

** np_{i0} is less than one, but the test statistic is significant without $(n_1 - np_{10})^2/np_{10}$.

Table (27) Tail Terminal Length of Osborne Cyst from Horsenettle Weed

$\bar{x} = 24.1044$ $s = 2.764$

Boundaries	m_i	n_i	$\frac{x_i - \bar{x}}{s} = Z_i$	Area to the Left of Z_i	$A_i = p_{i0}$	np_{i0}	$\frac{(n_i - np_{i0})^2}{np_{i0}}$
$x \leq 19$	18	2	-1.8467	0.03238	0.03238	3.72370	0.79790
$x \leq 21$	20	15	1.12316	0.13076	0.09838	11.31370	1.20109
$x \leq 23$	22	24	-0.39957	0.34458	0.21382	24.58930	0.01412
$x \leq 25$	24	31	0.32402	0.62703	0.28245	32.48175	0.06759
$x \leq 27$	26	22	1.04760	0.85267	0.22564	25.94860	0.60085
$x \leq 29$	28	19	1.77120	0.96172	0.10905	12.54075	3.32691
$29 < x$	30	2	2.49480	1.00000	0.38280	4.40220	1.31084
Sum		115			1.00000	115.00000	7.31930

$\chi^2 = 7.31930$

$\chi^2_{4(0.05)} = 9.488$

Table (28) Tail Length of Osborne Cyst from Hicks Variety Tobacco

$\overline{x} = 50.2739$ $\qquad$ $s = 3.4414$

Boundaries	m_i	n_i	$\frac{x_i - \overline{x}}{s} = Z_i$	Area to the Left of Z_i	$A_i = p_{i0}$	np_{i0}	$\frac{(n_i - np_{i0})^2}{np_{i0}}$
$x \leq 43.5$	42.5	5	-1.9684	0.02451	0.02451	2.81865	1.68814
$x \leq 45.5$	44.5	6	-1.3872	0.08269	0.05818	6.69070	0.07130
$x \leq 47.5$	46.5	13	-0.8060	0.21013	0.12744	14.65560	0.18703
$x \leq 49.5$	48.5	17	-0.2249	0.41103	0.20090	23.10350	1.61242
$x \leq 51.5$	50.5	33	0.3563	0.63919	0.22816	26.23840	1.74246
$x \leq 53.5$	52.5	21	0.9374	0.82572	0.18653	21.45095	0.00948
$x \leq 55.5$	54.5	13	1.5186	0.93556	0.10984	12.63160	0.01074
$x \leq 57.5$	56.5	7	2.0998	1.00000	0.06444	7.41060	0.02275
Sum		115			1.00000	115.00000	5.34433

$\chi^2 = 5.34433$

$\chi^2_{5(0.05)} = 11.07$

Table (29) Stylet Length of Horsenettle Cyst from Horsenettle Weed

$\bar{x} = 24.0826$ $s = 0.9079$

Boundaries	m_i	n_i	$\frac{x_i - \bar{x}}{s} = Z_i$	Area to the Left of Z_i	$A_i = p_{i0}$	np_{i0}	$\frac{(n_i - np_{i0})^2}{np_{i0}}$
$x \leq 22$	21.5	3	-2.2939	0.01090	0.01090	1.25350	2.43340
$x \leq 23$	22.5	15	-1.1924	0.11655	0.10565	12.14975	0.66865
$x \leq 24$	23.5	16	-0.0910	0.46374	0.34719	39.92685	14.33858
$x \leq 25$	24.5	76	1.0105	0.84386	0.38012	43.71380	23.84599
$x \leq 26$	25.5	3	2.1119	0.98265	0.13879	15.96085	10.52473
$x \leq 27$	26.5	2	3.2134	1.00000	0.01735	1.99525	0.00001
Sum		115			1.00000	115.00000	51.81136

$\chi^2 = 51.81136$*

$\chi^2_{3(0.05)} = 7.815$

Chapter III

TEST OF HOMOGENEITY OF VARIANCES

The test of the differences among the effects of the different treatments in a factorial experiment is based on the assumption of the normality of all treatments populations, and on the assumption of homogeneity of the variances of the populations. Thus, the investigation was made to determine whether the variances of the host - nematode combination of each of the measurements body length, width, tail length, and the tail terminal length could be considered to be equal.

This chapter will be divided into four sections. In the first section, the maximum likelihood ratio test of homogeneity of variances will be derived. In the second section, Bartlett's test of homogeneity of variances, which is a modification of the maximum likelihood ratio test, will be described. In the third section, the numerical results of Bartlett's test will be given, and in the fourth section, Cochran's test of homogeneity of variances will be described and numerical results of Cochran's test will be given.

3.1 Maximum Likelihood Ratio Test

Let $x_{11},x_{12},\ldots,x_{1n_1},\ldots,\ldots,\ldots,x_{i1},x_{i2},\ldots,x_{in_i},\ldots,$ x_{kn_k}, be k random samples from k normal populations, with unspecified means, $\mu_1, \mu_2, \ldots, \mu_k$ and unspecified variances $\sigma_1^2, \sigma_2^2, \ldots, \sigma_k^2$, $-\infty < \mu_i < \infty$, $0 \leq \sigma_i^2$, $i=1, 2, \ldots, k$, $\sum_{i=1}^{k} n_i = N$. The joint density function of the N observations is:

$$L(x_{11}, x_{12}, \ldots, x_{kn_k}) = \prod_{i=1}^{k} \left[\frac{1}{2\pi\sigma_i^2}\right]^{\frac{n_i}{2}} e^{-\frac{1}{2\sigma_i^2} \sum_{j=1}^{n_i} (x_{ij}-\mu_i)^2} . \tag{3.1.1}$$

To test the hypothesis H_0: $\sigma_1^2 = \sigma_2^2 = \ldots = \sigma_k^2 = \sigma^2$ against H_a: $\sigma_1^2 \neq \sigma_2^2 \neq \ldots \neq \sigma_k^2$, the maximum likelihood ratio procedure may be used. Let the parameter space restricted by H_0: be defined as ω, and let the unrestricted parameter space be defined as Ω. Then

$$L(\omega) = \left(\frac{1}{2\pi\sigma^2}\right)^{\frac{N}{2}} e^{-\frac{1}{2\sigma^2} \sum_{i=1}^{k} \sum_{j=1}^{n_i} (x_{ij}-\mu_i)^2} . \tag{3.1.2}$$

To get the maximum likelihood function in ω, differentiate $\log L(\omega)$ with respect to μ_i's $i=1,2,\ldots,k$, and with respect to σ^2. Now

$$\log L(\omega) = -\frac{N}{2} \log(2\pi) - \frac{N}{2} \log \sigma^2 - \frac{1}{2\sigma^2} \sum_{i=1}^{k} \sum_{j=1}^{n_i} (x_{ij}-\mu_i)^2 . \tag{3.1.3}$$

After setting the partial derivatives equal to zero,

$$\hat{\mu}_i = \bar{x}_i , \tag{3.1.4}$$

and

$$\hat{\sigma}^2 = \frac{\sum_{i=1}^{k} \sum_{j=1}^{n_i} (x_{ij}-\bar{x}_i)^2}{N} , \tag{3.1.5}$$

and the maximum likelihood function in ω is:

$$L(\hat{\omega}) = \left(\frac{1}{2\pi}\right)^{\frac{N}{2}} \left[\frac{N}{\sum_{i=1}^{k} \sum_{j=1}^{n_i} (x_{ij}-\bar{x}_i)^2}\right]^{\frac{N}{2}} e^{-\frac{N}{2}} . \qquad (3.1.6)$$

In Ω the joint density function is:

$$L(\hat{\Omega}) = \prod_{i=1}^{k} \frac{1}{2\pi\sigma_i^2}^{n_i/2} e^{-\frac{1}{2}\sum_{j=1}^{n_i} \frac{(x_{ij}-\mu_i)}{\sigma_i^2}} \qquad (3.1.7)$$

To get the maximum likelihood function in Ω, differentiate log $L(\Omega)$ with respect to μ_i's and with respect to σ_i^2's, $i=1,2,\ldots,k$. Now

$$\log L(\Omega) = -\frac{N}{2}\log(2\pi) - \frac{1}{2}\sum_{i=1}^{k} n_i \log \sigma_i^2 - \frac{1}{2}\sum_{i=1}^{k}\sum_{j=1}^{n_i}\frac{(x_{ij}-\mu_i)^2}{\sigma_i^2} . \qquad (3.1.8)$$

After setting the partial derivatives equal to zero,

$$\hat{\mu}_i = \bar{x}_i , \quad i=1,2,\ldots,k, \qquad (3.1.9)$$

and

$$\hat{\sigma}_i^2 = \sum_{j=1}^{n_i}\frac{(x_{ij}-\bar{x}_i)^2}{n_i} , \quad i=1,2,\ldots,k, \qquad (3.1.10)$$

and the maximum likelihood function in (Ω) is:

$$L(\hat{\Omega}) = \left(\frac{1}{2\pi}\right)^{\frac{N}{2}} e^{-\frac{N}{2}} \prod_{i=1}^{k}\left[\frac{n_i}{\sum_{j=1}^{n_i}(x_{ij}-\bar{x}_i)^2}\right]^{n_i/2} . \qquad (3.1.11)$$

Then the maximum likelihood ratio is:

$$\lambda = \frac{L(\hat{\omega})}{L(\hat{\Omega})} = \prod_{i=1}^{k}\left(\frac{\hat{\sigma}_i}{\sigma^2}\right)^{n_i/2} . \qquad (3.1.12)$$

λ will be distributed on the interval $(0,1)$, and H_0 will be rejected for small value of λ.

Under H_0, $-2 \log \lambda$ has asymptotically a χ^2 distribution, degrees of freedom equal to the difference between the dimensions of Ω and ω, which is equal to the number of parameters estimated in Ω minus the number of parameters estimated in ω. Therefore, for this case the degrees of freedom equal k-1.

The rejection region of H_0 contains the small values of λ, which is equivalent to the large values of $\chi^2_{(k-1)}$. As n increases, the approximation of χ^2 distribution is improved.

3.2 Bartlett's Test of Homogeneity of Variances

M. S. Bartlett [8] in 1937 modified the maximum likelihood ratio test. In this modification, the biased maximum likelihood estimators $\hat{\sigma}_i^2$ and $\hat{\sigma}^2$ in (3.1.10) were replaced by the unbiased estimators

$$\hat{\hat{\sigma}}_i = \frac{1}{n_i-1} \sum_{j=1}^{n_i} (x_{ij}-\bar{x}_i)^2, \qquad (3.2.1)$$

and

$$\hat{\hat{\sigma}}^2 = \frac{1}{n-k} \sum_{i=1}^{k} \sum_{j=1}^{n_i} (x_{ij}-\bar{x}_i)^2 \qquad (3.2.2)$$

respectively, and the exponent (n_i) of $\left(\frac{\hat{\hat{\sigma}}_i}{\hat{\hat{\sigma}}^2}\right)$ is changed to $(n_i - 1)$.

The modified test statistic will be:

$$\lambda^{*} \prod_{i=1}^{k} \left(\frac{\hat{\hat{\sigma}}_i}{\hat{\hat{\sigma}}^2}\right)^{\frac{n_i-1}{2}} , \qquad (3.2.3)$$

and

$$-2 \log \lambda^* = (n-k) \log \hat{\sigma}^2 - \sum_{i=1}^{k} (n_i - 1) \log \hat{\sigma}_i^2. \tag{3.2.4}$$

The expected value of $-2 \log \lambda^*$ is:

$$(k-1) + \left(\sum_{i=1}^{k} \frac{1}{n_i-1} - \frac{1}{n-k}\right), \tag{3.2.5}$$

and to adjust the mean of $-2 \log \lambda^*$ to be equal to the mean of χ^2 with (k-1) degree of freedom, (3.2.4) should be divided by a correction factor

$$c = 1 + \frac{1}{3(k-1)} \left[\sum_{i=1}^{k} \frac{1}{n_i-1} - \frac{1}{n-k} \right]. \tag{3.2.6}$$

Thus, the corrected test statistic is:

$(-2 \log \lambda^*)/c =$

$$\frac{1}{c}\left[(n-k) \log \frac{1}{n-k} \sum_{i=1}^{k} \sum_{j=1}^{n_i} (x_{ij}-\bar{x}_i)^2 - \sum_{i=1}^{k} (n_i-1) \log \sum_{j=1}^{n_i} \frac{(x_{ij}-\bar{x}_i)^2}{n_i-1}\right], \tag{3.2.7}$$

which has an exact χ^2 distribution with (k-1) degree of freedom, and the test is valid for all sample sizes.

The calculations of the test statistic are presented systematically in Table (30).

Table (30) Calculation for the Test Statistic of

Bartlett's Test of Homogeneity of Variances

Sample	$\sum_{j=1}^{n_i}(x_{ij}-\bar{x}_i)^2$	D.F	$\frac{1}{D.F}$	$\sum_{j=1}^{n_i}\frac{(x_{ij}-\bar{x}_i)^2}{D.F}$	$\log_{10}\sum_{j=1}^{n_i}\frac{(x_{ij}-\bar{x}_i)^2}{D.F}$	$D.F.\log_{10}\sum_{j=1}^{n_i}\frac{(x_{ij}-\bar{x}_i)^2}{D.F}$
1	$\sum_{j=1}^{n_i}(x_{1j}-\bar{x}_1)^2$	n_1-1	$\frac{1}{n_1-1}$	$\sum_{j=1}^{n_1}\frac{(x_{1j}-\bar{x}_1)^2}{n_1-1}$	$\log_{10}\sum_{j=1}^{n_1}\frac{(x_{1j}-\bar{x}_1)^2}{n_1-1}$	$(n_1-1)\log_{10}\sum_{j=1}^{n_1}\frac{(x_{1j}-\bar{x}_1)^2}{n_1-1}$
2	$\sum_{j=1}^{n_2}(x_{2j}-\bar{x}_2)^2$	n_2-1	$\frac{1}{n_2-1}$	$\sum_{j=1}^{n_2}\frac{(x_{2j}-\bar{x}_2)^2}{n_2-1}$	$\log_{10}\sum_{j=1}^{n_2}\frac{(x_{2j}-\bar{x}_2)^2}{n_2-1}$	$(n_2-1)\log_{10}\sum_{j=1}^{n_2}\frac{(x_{2j}-\bar{x}_2)^2}{n_2-1}$
–	–	–	–	–	–	–
k	$\sum_{j=1}^{n_k}(x_{kj}-\bar{x}_k)^2$	n_k-1	$\frac{1}{n_k-1}$	$\sum_{j=1}^{n_k}\frac{(x_{kj}-\bar{x})^2}{n_k-1}$	$\log_{10}\sum_{j=1}^{n_k}\frac{(x_{kj}-\bar{x}_k)^2}{n_k-1}$	$(n_k-1)\log_{10}\sum_{j=1}^{n_k}\frac{(x_{kj}-\bar{x}_k)^2}{n_k-1}$
Sum	$(n-k)\hat{\hat{\sigma}}^2$	$n-k$	$\sum_{i=1}^{k}\frac{1}{n_i-1}$		$\sum_{i=1}^{k}\log_{10}\ i^2$	$\sum_{i=1}^{k}(n_i-1)\log_{10}\ i^2$
χ^2_{k-1}	$\log_e 10\,[(n-k)\log\hat{\hat{\sigma}}^2 - \sum_{i=1}^{k}(n_i-1)\log_{10}\hat{\hat{\sigma}}_i^{\,2}]$					
c	$1+\frac{1}{3(k-1)}[\sum_{i=1}^{k}\frac{1}{n_i-1}-\frac{1}{N-K}]$				Corrected χ^2_{k-1}	$\chi^2_{k-1} \div c$

3.3 Numerical Results

Bartlett's test of homogeneity of variances was made for the host - nematode combinations which satisfied the assumption of normality. These combinations are for the measurements of body length, width, tail length, and tail terminal length. The corrected χ^2-value is given at the bottom of the tables and significance is indicated by an asterisk. The calculations were made using both the IBM 1620 and a desk calculator. Although eight decimal places were used in the calculations, the numbers have been rounded for presentation. In each of Tables (31), (32), (33), and (34), there are four samples, resulting in a χ^2 with three degrees of freedom if H_0 is true. The critical value for the test statistic at 0.05 level is 7.815, and from these tables it can be seen that the corrected χ^2-value was significant for the tail terminal length.

3.4 Cochran's Test of Homogeneity of Variances

To test the homogeneity of variances of k samples from normal distributions, and of equal sizes, W. G. Cochran [1] designed a test statistic especially for the case where one variance is much larger than the others. The test statistic is:

$$c = \frac{\text{largest variance}}{\text{sum of variances}}$$

The hypothesis of equal variances is rejected if the computed value of the test statistic exceeds a critical value. The

Table (31) Computation of Bartlett's Test of Homogeneity of Variances for the Host - Nematode Combinations of Body Length Measurements

Sample	$\sum_{j=1}^{n_i}(x_{ij}-\bar{x}_i)^2$	D.F	$\frac{1}{D.F}$	$\sum_{j=1}^{n_i}\frac{(x_{ij}-\bar{x}_i)^2}{D.F}$	$\log_{10}\sum_{j=1}^{n_i}\frac{(x_{ij}-\bar{x}_i)^2}{D.F}$	$D.F\log\frac{\sum_{j=1}^{n_i}(x_{ij}-\bar{x}_i)^2}{D.F}$
Horsenettle Cyst from Horsenettle Weed	114564.11	114	0.00877	1004.94830	3.00214	342.24439
Horsenettle Cyst from Tobacco	80194.22	114	0.00877	703.45807	2.84724	324.58517
Osborne Cyst from Tobacco	109168.67	114	0.00877	957.61991	2.98119	339.85602
Osborne Cyst from Horsenettle Weed	116869.68	114	0.00877	1025.17260	3.01080	343.23085
Sum	420796.68	456	0.03508	3691.19880	11.84137	1349.91640

χ^2 = 5.00260

c = 1.00365497

Corrected χ^2 = 4.984379

χ^2 = 4.98438

Table (32) Computations of Bartlett's Test for Homogeneity of Variances for the Host - Nematode Combinations of the Width Measurements

Sample	$\sum_{j=1}^{n_i}(x_{ij}-\bar{x}_i)^2$	D.F	$\frac{1}{D.F}$	$\frac{\sum_{j=1}^{n_i}(x_{ij}-\bar{x}_i)^2}{D.F}$	$\log_{10}\frac{\sum_{j=1}^{n_i}(x_{ij}-\bar{x}_i)^2}{D.F}$	D.F $\log_{10}\frac{\sum_{j=1}^{n_i}(x_{ij}-x_i)^2}{D.F}$
Horsenettle Cyst from Horsenettle Weed	263.52	114	0.00877	2.31154	0.36390	41.48485
Horsenettle Cyst from Tobacco	243.11	114	0.00877	2.13256	0.32890	37.49479
Osborne Cyst from Horsenettle Weed	259.83	114	0.00877	2.279223	0.35779	40.78781
Osborne Cyst from Tobacco	209.43	114	0.00877	1.83714	0.26414	30.11224
Sum	975.89	456	0.03508	8.56047	1.31473	149.87969

χ^2 = 1.84211
c = 1.00365497
Corrected χ^2 = 1.8354

χ^2 = 1.8354

Table (33) Computation of Bartlett's Test of Homogeneity of Variances of the Host - Nematode Combinations of the Tail Measurements

Sample	$\sum_{j=1}^{n_i}(x_{ij}-\bar{x}_i)^2$	D.F	$\frac{1}{D.F}$	$\frac{\sum_{j=1}^{n_i}(x_{ij}-\bar{x}_i)^2}{D.F}$	$\log_{10}\frac{\sum_{j=1}^{n_i}(x_{ij}-\bar{x}_i)^2}{D.F}$	$D.F \log_{10}\frac{\sum_{j=1}^{n_i}(x_{ij}-\bar{x}_i)^2}{D.F}$
Horsenettle Cyst from Horsenettle Weed	1641.76	114	0.00877	14.40140	1.15841	132.05814
Horsenettle Cyst from Tobacco	1099.91	114	0.00877	9.64833	0.98445	112.22757
Osborne Cyst from Horsenettle Weed	1771.66	114	0.00877	15.54088	1.19148	135.82820
Osborne Cyst from Tobacco	1443.03	114	0.00877	12.65816	1.10237	125.67025
Sum	5956.36	456	0.03508	52.24877	4.43671	505.78416

χ^2 = 7.18229
c = 1.00365497
Corrected χ^2 = 7.156135

χ^2 = 7.156135

Table (34) Computations of Bartlett's Test of Homogeneity of Variances of the Host - Nematode Combinations of Tail Terminal Measurements

Sample	$\sum_{j=1}^{n_i}(x_{ij}-\bar{x}_i)^2$	D.F	$\frac{1}{D.F}$	$\frac{\sum_{j=1}^{n_i}(x_{ij}-\bar{x}_i)^2}{D.F}$	$\log_{10}\frac{\sum_{j=1}^{n_i}(x_{ij}-\bar{x}_i)^2}{D.F}$	$D.F \log_{10}\frac{\sum_{j=1}^{n_i}(x_{ij}-\bar{x}_i)^2}{D.F}$
Horsenettle Cyst from Horsenettle Weed	1244.41	114	0.00877	10.91588	1.03806	118.33867
Horsenettle Cyst from Tobacco	811.45	114	0.00877	7.11796	0.85236	97.16850
Osborne Cyst from Horsenettle Weed	844.77	114	0.00877	7.41025	0.86983	99.16091
Osborne Cyst from Tobacco	1664.13	114	0.00877	14.59759	1.16428	132.72803
Sum	4564.75	456	0.03508	40.04168	3.92453	447.39611

$\chi^2 = 20.28612$

$c = 1.00365497$

Corrected $\chi^2 = 20.212245$

$\chi^2 = 20.212245$*

critical values are tabulated for the 0.05 and 0.01 levels of significance in [1].

In Table (35) Cochran's test of homogeneity of variances was made for the host - nematode combinations for each of the measurements, body length, width, tail length, and tail terminal length. The critical value for the test statistic for four samples each of size 115 and at 0.05 level of significance is 0.3262. The significance is indicated by an asterisk. From this table it can be seen that the test statistic was significant for the host - nematode combinations of the tail terminal length.

Table (35) Computation of Cochran's Test for Homogeneity of Variances for the Host - Nematode Combinations for each of the Measurements of Body Length, Width, Tail Length and Tail Terminal Length

Measurement	Name of the Combination of largest Variance	Largest variance	Sum of the variances	c
Body Length	Osborne Cyst from Horsenettle Weed	1025.17260	3691.19880	0.27773
Width	Horsenettle Cyst from Horsenettle Weed	2.31154	8.56047	0.27003
Tail Length	Osborne Cyst from Horsenettle Weed	15.54088	52.24877	0.29744
Tail Terminal Length	Osborne Cyst from Tobacco	14.59759	40.04167	0.36456*

Chapter IV

TWO WAY FACTORIAL ANALYSIS

Since for the host - nematode combinations, the measurements, body length, width, and tail length could be considered normally distributed, with a common variance, an investigation was made of the differences between the two nematodes, between the two hosts, and interaction effect between the hosts and the nematodes.

This chapter will be divided into three sections. In the first section, the maximum likelihood ratio test of analysis of variances will be derived, in the second section the test statistic for testing the interaction and the main effect will be derived. Although these derivations are given in many standard text books such as Kempthorne [7], and Kendall [8], it was decided to reproduce them here for completeness. In the third section, the numerical results of analysis of variance will be given.

4.1 Maximum Likelihood Ratio Test

Let x_{111}, x_{112}, ..., x_{11n}, ..., ..., ..., x_{rcn} be (rc) random samples each of size n, from (rc) normal populations, with unspecified means μ_{11}, μ_{12}, ..., μ_{rc}, $-\infty < \mu_{ij} < \infty$, $i=1,2,\ldots,r$, $j=1,2,\ldots,c$, and with unspecified common variance σ^2, $0 \leq \sigma^2$. The joint density function of the N(=rcn) observations is:

$$L = \left(\frac{1}{2\pi\sigma^2}\right)^{\frac{N}{2}} e^{-\frac{1}{2\sigma^2} \sum_{i=1}^{r} \sum_{j=1}^{c} \sum_{k=1}^{n} (x_{ijk}-\mu_{ij})^2} . \quad (4.1.1)$$

To test the hypothesis H_0: $\mu_{ij}=\mu_{ij}^*$, where μ_{ij}^* is a specified value, $i=1,2,\ldots r$, $j=1,2,\ldots c$ against H_a: $\mu_{ij} \neq \mu_{ij}^*$, the maximum likelihood procedure may be used. Let the parameter space restricted by H_0 be defined as ω, and let the unrestricted parameter space be defined as Ω. Then

$$L(\omega) = \left(\frac{1}{2\pi\sigma^2}\right)^{\frac{N}{2}} e^{-\frac{1}{2\sigma^2} \sum_{i=1}^{r} \sum_{j=1}^{c} \sum_{k=1}^{n} (x_{ijk}-\mu_{ij}^*)^2} . \quad (4.1.2)$$

To get the maximum likelihood function in ω, differentiate log $L(\omega)$ with respect to σ^2, the unspecified parameter in ω

$$\text{Log } L(\omega) = -\frac{N}{2}\log\sigma^2 - \frac{N}{2}\log(2\pi) - \frac{1}{2\sigma^2} \sum_{i=1}^{r} \sum_{j=1}^{c} \sum_{k=1}^{n} (x_{ijk}-\mu_{ij}^*)^2 . \quad (4.1.3)$$

After setting the partial derivates equal to zero,

$$\hat{\sigma}_2 = \frac{\sum_{i=1}^{r} \sum_{j=1}^{c} \sum_{k=1}^{n} (x_{ijk}-\mu_{ij}^*)^2}{N} , \quad (4.1.4)$$

and the maximum likelihood function in ω is:

$$L(\hat{\omega}) = \left[\frac{N}{2\pi \sum_{i=1}^{r} \sum_{j=1}^{c} \sum_{k=1}^{n} (x_{ijk}-\mu_{ij}^*)^2}\right]^{\frac{N}{2}} e^{-\frac{N}{2}} . \quad (4.1.5)$$

To get the maximum likelihood function in Ω, differentiate log $L(\Omega)$ with respect to the unspecified parameters

μ_{ij}'s, i=1,2,...,r, j=1,2,...,c, and with respect to σ^2.

Now

$$\text{Log } L(\Omega) = -\frac{N}{2}\log(2\pi) - \frac{N}{2}\log\sigma^2 - \frac{1}{2\sigma^2}\sum_{i=1}^{r}\sum_{j=1}^{c}\sum_{k=1}^{n}(x_{ijk}-\mu_{ij})^2. \tag{4.1.6}$$

After setting the partial derivatives equal to zero,

$$\hat{\mu}_{ij} = \bar{x}_{ij}, \tag{4.1.7}$$

where $\bar{x}_{ij}$ is the mean of the ith jth cell, and

$$\hat{\sigma}^2 = \frac{\sum_{i=1}^{r}\sum_{j=1}^{c}\sum_{k=1}^{n}(x_{ijk}-\bar{x}_{ij})^2}{N}, \tag{4.1.8}$$

and the maximum likelihood function in Ω is:

$$L(\hat{\Omega}) = \left(\frac{1}{2\pi}\right)^{\frac{N}{2}}\left[\frac{N}{\sum_{i=1}^{r}\sum_{j=1}^{c}\sum_{k=1}^{n}(x_{ijk}-\bar{x}_{ij})^2}\right]^{\frac{N}{2}} e^{-\frac{N}{2}}. \tag{4.1.9}$$

Then the maximum likelihood ratio is:

$$\lambda = \frac{L(\hat{\omega})}{L(\hat{\Omega})} = \left[\frac{\sum_{i=1}^{r}\sum_{j=1}^{c}\sum_{k=1}^{n}(x_{ijk}-\bar{x}_{ij})^2}{\sum_{i=1}^{r}\sum_{j=1}^{c}\sum_{k=1}^{n}(x_{ijk}-\mu_{ij}^*)^2}\right]^{\frac{N}{2}}. \tag{4.1.10}$$

Let (S) be defined as:

$$S = \sum_{i=1}^{r}\sum_{j=1}^{c}\sum_{k=1}^{n}(x_{ijk}-\mu_{ij})^2 . \tag{4.1.11}$$

Since the value of $S = \sum_{i=1}^{r}\sum_{j=1}^{c}\sum_{k=1}^{n}(x_{ijk}-\bar{x}_{ij})^2$ maximizes $L(\Omega)$

therefore the value

$$\sum_{i=1}^{r} \sum_{j=1}^{c} \sum_{k=1}^{n} (x_{ijk}-\bar{x}_{ij}^{*})^2,$$

is the minimum value of S in Ω, and since the value of

$$S = \sum_{i=1}^{r} \sum_{j=1}^{c} \sum_{k=1}^{n} (x_{ijk}-\mu_{ij}^{*})^2 \text{ maximizes } L(\omega),$$

therefore the value

$$\sum_{i=1}^{r} \sum_{j=1}^{c} \sum_{k=1}^{n} (x_{ijk}-\mu_{ij}^{*})^2,$$

is the minimum value of S in ω, then the maximum likelihood ratio can be written as:

$$\lambda = \left[\frac{\text{minimum value of S in}\Omega}{\text{minimum value of S in } \omega}\right]^{\frac{N}{2}} \qquad (4.1.12)$$

which is distributed on interval (0,1).

H_0 will be rejected for the small values of λ.

Let λ^* be defined as:

$$\lambda^* = \frac{1}{\lambda^{2/N}} - 1 = \left[\frac{\text{minimum S in } \omega - \text{minimum S in } \Omega}{\text{minimum S in } \Omega}\right], \qquad (4.1.13)$$

then under H_0 $\frac{1}{\sigma^2}$\{minimum S in ω - minimum S in Ω\} has a χ^2 distribution with ν_1 degree of freedom. $\frac{1}{\sigma^2}$\{minimum S in Ω\} has a χ^2 distribution with ν_2 degree of freedom, and independent of the numerator, then

$$F = \frac{\nu_2}{\nu} \lambda^* = \frac{(\text{Minimum S in } \omega - \text{minimum S in } \Omega)/\nu_1}{(\text{minimum S in } \Omega)/\nu_2}, \qquad (4.1.14)$$

under H_0 has F distribution with (ν_1,ν_2) degrees of freedom.

H_0 will reject for small values of λ, which are equivalent to the large values of F.

4.2 Maximum Likelihood Ratio Test for Testing the Interaction and the Main Effects

Let the two factors be factor A with r levels, and factor B with c levels, so there is (r x c) cells, each containing n observations. We assume all the rcn observations are distributed normally with common variance σ^2, and that they are independent of each other.

The mathematical model is:

$$x_{ijk} = \mu + \alpha_i + \beta_j + (\alpha\beta)_{ij} + e_{ijk}, \qquad (4.2.1)$$

$i = 1, 2, \ldots, r$, $j = 1, 2, \ldots, c$, $k = 1, 2, \ldots, n$,

where μ = the overall effect,

α_i = the effect due the <u>ith</u> level of factor A,

β_j = the effect due the <u>jth</u> level of factor B,

$(\alpha\beta)_{ij}$ = the effect due the interaction between the <u>ith</u> treatment of factor A with the <u>jth</u> treatment of factor B,

e_{ijk} = the experimental random error.

We assume all e_{ijk}'s $\sim N(0, \sigma^2)$. The expected value of x_{ijk} is $E(x_{ijk}) = \mu + \alpha_i + \beta_j + (\alpha\beta)_{ij}$. (4.2.2)

Then the value of S defined in (4.1.13) will be:

$$S = \sum_{i=1}^{r} \sum_{j=1}^{c} \sum_{k=1}^{n} (x_{ijk} - \mu - \alpha_i - \beta_j - (\alpha\beta)_{ij})^2. \qquad (4.2.3)$$

4.2.1 Test of the Interaction Effect

To test the hypothesis H_0: $(\alpha\beta)_{ij}$'s are equal for all $i = 1, 2, \ldots, r$, $j=1, 2, \ldots, c$, against H_a: $(\alpha\beta)_{ij}$'s are not equal, the test statistic F defined in (4.1.13) will be used. To get the unique minimum value of S defined in (4.2.3) in the unrestricted parameter space (Ω), differentiate S with respect to the parameters μ, α_i's, β_j's and to $(\alpha\beta)_{ij}$'s subject to the restriction for the unique solution

$$\sum_{i=1}^{r} \alpha_i = \sum_{j=1}^{c} \beta_j = \sum_{i=1}^{r} (\alpha\beta)_{ij} = \sum_{j=1}^{c} (\alpha\beta)_{ij} = 0 . \qquad (4.2.4)$$

After setting the partial derivatives equal to zero,

$$\hat{\mu} = \bar{x}_{\cdots}, \qquad (4.2.5)$$

$$\hat{\alpha}_i = \bar{x}_{i\cdot\cdot} - \bar{x}_{\cdots}, \qquad (4.2.6)$$

$$\hat{\beta}_j = \bar{x}_{\cdot j\cdot} - \bar{x}_{\cdots}, \qquad (4.2.7)$$

$$(\widehat{\alpha\beta})_{ij} = (\bar{x}_{ij\cdot} - \bar{x}_{i\cdot\cdot} - \bar{x}_{\cdot j\cdot} + \bar{x}_{\cdots}), \qquad (4.2.8)$$

where $\bar{x}_{\cdots}$, $\bar{x}_{i\cdot\cdot}$, $\bar{x}_{\cdot j\cdot}$ and $\bar{x}_{ij\cdot}$ are the overall mean, the ith row treatment mean, the jth column treatment mean, and the ith cell mean respectively.

Then the minimum value of S in Ω is:

$$\sum_{i=1}^{r} \sum_{j=1}^{c} \sum_{k=1}^{n} (x_{ijk} - \bar{x}_{ij})^2 , \qquad (4.2.9)$$

$\frac{1}{\sigma^2}$ minimum S in Ω is distributed as a χ^2 with $(N - rc)$ degree of freedom, and it will be called the sum of squares within treatments, or error sum of squares.

Under H_0, and applying the restriction (4.2.4), the hypothesis can be written as H_0: $(\alpha\beta)_{ij} = 0$ $i=1,2,\dots r$, $j=1,2,\dots,c$, H_a: $(\alpha\beta)_{ij} \neq 0$, and S defined in (4.2.3) can be written as

$$\sum_{i=1}^{r} \sum_{j=1}^{c} \sum_{k=1}^{n}(x_{ijk} - \mu - \alpha_i - \beta_i)^2. \qquad (4.2.10)$$

To get the unique minimum value of S in ω, differentiate (4.2.10) with respect to the parameters μ, α_i's and β_j's subject to the restriction (4.2.4)

After setting the partial derivatives equal to zero,

$$\hat{\mu} = \bar{x}_{\dots} , \dots \qquad (4.2.11)$$

$$\hat{\alpha}_i = \bar{x}_{i\dots} - \bar{x}_{\dots}, \qquad (4.2.12)$$

$$\hat{\beta}_j = \bar{x}_{.j.} - \bar{x}_{\dots}, \qquad (4.2.13)$$

where $\bar{x}_{\dots}$, $\bar{x}_{i\dots}$, $\bar{x}_{.j.}$ are as defined before.
Then the minimum value of S in ω is:

$$\sum_{i=1}^{r} \sum_{j=1}^{c} \sum_{k=1}^{n} (x_{ijk} - \bar{x}_{i\dots} - x_{.j.} + \bar{x}_{\dots})^2. \quad (4.2.14)$$

Now

minimum S in ω - minimum S in Ω is:

$$n \sum_{i=1}^{r} \sum_{j=1}^{c} \sum_{k=1}^{n}(\bar{x}_{ij.} - \bar{x}_{i\dots} - \bar{x}_{.j.} + \bar{x}_{\dots})^2, \qquad (4.2.15)$$

which is independent of minimum S in Ω, and under H_0, $\frac{1}{\sigma^2}$\{minimum S in ω - minimum S in Ω\} has χ^2 distribution with (r-1)(c-1) degree of freedom, and it will be called the sum of squares due to interaction.

Then the test statistic F defined in (4.1.14) is

$$F = \frac{[\text{minimum } S \text{ in } \omega - \text{minimum } S \text{ in } \Omega]/\nu_1}{[\text{minimum } S \text{ in } \Omega]/\nu_2}$$

$$= \frac{[n \sum_{i=1}^{r} \sum_{j=1}^{c} (\bar{x}_{ij.} - \bar{x}_{i..} - \bar{x}_{.j.} + \bar{x}_{...})^2]/(r-1)(c-1)}{[\sum_{i=1}^{r} \sum_{j=1}^{c} \sum_{k=1}^{n} (x_{ijk} - \bar{x}_{ij.})^2]/N-rc}, \quad (4.2.16)$$

and under H_0 has a F distribution with $(r-1)(c-1)$, $(N-rc)$ degrees of freedom.

4.2.2 Testing the Differences Among the Effects of Factor A Treatments

To test the hypothesis H_0: α_i's are equal against H_a: α_i's are not equal, given $(\alpha\beta)_{ij} = 0$ $i = 1,2,\ldots,r$, $j = 1,2,\ldots,c$, the test statistic F defined in (4.1.14) will be used. When the restriction (4.1.4) for the unique solution is applied, then the above hypothesis can be written as H_0: $\alpha_i = 0$ and H_a: $\alpha_i \neq 0$ $i = 1, 2, \ldots, r$.

Now the value of S in ω is:

$$\sum_{i=1}^{r} \sum_{j=1}^{c} \sum_{k=1}^{n} (x_{ijk} - \mu - \beta_j)^2. \quad (4.2.17)$$

To get the minimum value of S in ω, differentiate (4.2.17) with respect to the parameters μ, β_j's, subject to the restriction (4.2.4).

After setting the partial derivatives equal to zero,

$$\hat{\mu} = \overline{x}_{\cdot\cdot\cdot}, \tag{4.2.18}$$

$$\hat{\beta}_j = \overline{x}_{\cdot j \cdot} - \overline{x}_{\cdot\cdot\cdot}, \tag{4.2.19}$$

and $\overline{x}_{\cdot\cdot\cdot}$, $\overline{x}_{\cdot j \cdot}$ as before. Then the minimum value of S in ω is:

$$\sum_{i=1}^{r} \sum_{j=1}^{c} \sum_{k=1}^{n} (x_{ijk} - \overline{x}_{\cdot j \cdot})^2 \ . \tag{4.2.20}$$

Now the minimum S in ω - minimum S in Ω is:

$$nc \sum_{i=1}^{r} (\overline{x}_{i\cdot\cdot} - \overline{x}_{\cdot\cdot\cdot})^2, \tag{4.2.21}$$

which will be called the sum of squares between factor A.

Under H_0, $\frac{1}{\sigma^2}$\{minimum S in ω - minimum S in Ω\} has a χ^2 distribution, with (r-1) degree of freedom, and since it is independent of minimum S in Ω, then the test statistic

$$F = \frac{[nc\sum_{i=1}^{r} (\overline{x}_{i\cdot\cdot} - \overline{x})^2]/(r-1)}{[\sum_{i=1}^{r} \sum_{j=1}^{c} \sum_{k=1}^{n} (x_{ijk} - \overline{x}_{ij\cdot})^2]/(N-rc)} \ , \tag{4.2.22}$$

under H_o has F distribution with (r-1), (N-rc) degrees of freedom.

4.2.3 Testing the Differences Among the Effects of Factor B Treatments

The derivation of the test statistic for testing the hypothesis H_0: β_j's are equal against H_a: β_j's are not equal, given $(\alpha\beta)_{ij}$'s are zero, $i = 1,2,\ldots,r$, $j = 1,2,\ldots,c$, is done in the same manner as derivation of the test statistic for testing the effect of factor A treatments.

Applying the restriction (4.2.4), H_0 can be written $\beta_j = 0$, $j = 1,2,\ldots,c$, and H_a: not all the β_j's are zero.

The value of the sum of squares between the treatments of factor B will be:

$$\text{minimum } S \text{ in } \omega - \text{minimum } S \text{ in } \Omega = rn \sum_{j=1}^{r} (\bar{x}_{.j.} - \bar{x}_{...})^2, \tag{4.2.23}$$

independent of minimum S in Ω, and under H_0,

$$\frac{1}{\sigma^2}\{\text{minimum } S \text{ in } \omega - \text{minimum } S \text{ in } \Omega\} \text{ has a } \chi^2$$

distribution with (c-1) degree of freedom.

The test statistic is:

$$F = \frac{rn \sum_{j=1}^{r}(\bar{x}_{.j.} - \bar{x}_{...})^2/(c-1)}{\sum_{i=1}^{r} \sum_{j=1}^{c} \sum_{k=1}^{n} (x_{ijk} - \bar{x}_{ij.})^2/(N-rc)}, \tag{4.2.24}$$

which under H_0 has an F distribution with (c-1), (N-rc) degrees of freedom.

The practical computation forms for the sums of squares are:

(1) Sum of squares between factor A treatments is

$$S.S_A = \sum_{i=1}^{r} \frac{R_i^2}{nc} - \frac{G^2}{N}, \tag{4.2.25}$$

where $R_{i.}$ is the total of ith level of factor A, and G is the total of the rcn observations.

(2) Sum of squares between factor B treatments is

$$S.S_B = \sum_{j=1}^{c} \frac{C_{.j}^{\,2}}{nr} - \frac{G^2}{N} , \qquad (4.2.26)$$

where $C_{.j}$ is the total of the jth level of factor B.

(3) To compute the sum of squares for interaction, the sum of squares for the subtotal will be computed which is:

$$S.S_{Subtotal} = \sum_{k=1}^{n} \frac{W_{ij.}^{\,2}}{n} - \frac{G^2}{N} , \qquad (4.2.26)$$

where $W_{ij.}$ is the sum of the ijth cell, then the interaction sum of squares is

$$S.S_I = S.S_{Subtotal} - S.S_A - S.S_B \qquad (4.2.27)$$

(4) To compute the error sum of squares, first the total sum of squares will be computed which is

$$S.S_{Total} = \sum_{i=1}^{r} \sum_{j=1}^{c} \sum_{k=1}^{n} x_{ijk}^2 - \frac{G^2}{N} , \qquad (4.2.28)$$

then

$$S.S_E = S.S_T - S.S_{Subtotal} . \qquad (4.2.29)$$

The computation of test statistics for the previous hypotheses are presented systematically in Table (36).

Table (36) Computations of the Test Statistics for a Two Way Factorial Analysis

Sources	D.F	S.S	M.S	F
Interaction	$(r-1)(c-1)$	$\sum_{i=1}^{r}\sum_{j=1}^{c}\frac{W_{ij}^{2}}{n} - \frac{G^2}{N} - S.S_A - S.S_B$	$S.S_I/(r-1)(c-1)$ $= MSI$	MSI/MSE
Between factor A treatments	$(r-1)$	$\sum_{i=1}^{r}\frac{R_i^2}{nc} - \frac{G^2}{N}$	$S.S_A/(r-1)$ $= MSA$	MSR/MSE
Between factor B treatments	$(c-1)$	$\sum_{j=1}^{c}\frac{C_j^2}{rn} - \frac{G^2}{N}$	$S.S_B/(c-1) = MSB$	MSB/MSE
Error	$N-rc$	$S.S_T - S.S_{Subtotal}$	$S.S_E/(N-rc) = MSE$	
Total	$N-1$	$\sum_{i=1}^{r}\sum_{j=1}^{c}\sum_{k=1}^{n}(x_{ijk} - \bar{x}_{\cdots})^2$		

4.3 Numerical Results

In this section, the analyses of variance were made for the measurements: body length, width, and tail length. The sums of squares due to interaction, to differences between the two nematodes, to differences between the two hosts, to error, and the total were computed from (4.2.27), (4.2.25), (4.2.26), (4.2.29), and (4.2.28) respectively. The test statistics for testing the interaction effect, between nematodes effect, and between hosts effect, were computed from (4.2.16), (4.2.22), and (4.2.24) with degrees of freedom (1,456), (1,456) and (1,456) respectively. The critical value for each of the test statistics when H_0 is true is 6.68 and significance is indicated by an asterisk. It can be seen from Tables (37), (38), and (39) that the interaction effect is not significant for the host - nematode combinations for the measurements of body length, width, and tail length. With these results, it was possible to advance in the analysis and make the other two tests.

For the tests of the two main effects, it can be seen from the same tables that the difference between the hosts was significant for the measurement of body length, and the difference between the nematodes was significant for the measurements of width and body length. The tobacco effect is larger than the effect of the Horsenettle weed, and the Horsenettle cyst effect is larger than Osborne cyst effect for the measurement of the body length. Also it was found that the effect of the Osborne cyst is larger than the effect of Horsenettle cyst for the measurement of width.

Table (37)

Analyses of Variance for the Host - Nematode Combinations of the Measurements of Body Length

Sources	D.F	S.S	M.S	F
Interaction	1	92.70	92.7	-
Between Nematodes	1	6541.70	6541.7	7.08897*
Between Hosts	1	12037.20	12037.2	13.0442*
Error	456	420796.79	922.8	
Total SS	459	439468.39		

Table (38)

Analyses of Variance for the Host - Nematode Combinations for the Measurements of Width

Sources	D.F	S.S	M.S	F
Interaction	1	2.3663	2.3663	1.1057
Between Nematodes	1	147.8624	147.8624	69.0901*
Between Hosts	1	0.5032	0.5032	-
Error	456	975.9026	2.1401	-
Total SS	459	1126.6345		

Table (39)

Analyses of Variance for the Host - Nematode Combinations for the Measurements of the Tail

Sources	D.F	S.S	M.S	F
Interaction	1	13.125	13.125	1.0048
Between Nematodes	1	8.655	8.655	-
Between Hosts	1	8.383	8.383	-
Error	456	5956.337	13.062	-
Total SS	459	5986.500		

Chapter V

DISCRIMINATION ANALYSIS

This chapter is concerned with the possibility of discriminating between the host - nematode combinations on the basis of the measurements: body length, stylet length, gland orifice length, width, tail length, and tail terminal length. The main interest is in estimating the best linear combination of the six measurements for any two of the four host - nematode combinations.

In the first section the estimation of the best linear discriminant function will be derived. In the second section a test of the significance of the best discriminant function will be described. In section three, the probability of misclassification will be described, and in the fourth section, the numerical estimates of the discriminant functions, the testing the significance of these functions, and the probabilities of misclassification will be given.

Even though the assumptions required for discrimination analysis may not hold for these data, it was thought that in this preliminary work that some benefit could be gained from such an analysis. It is hoped that after discussing the results with Dr. Miller that his technique may be modified or that transformations of the data may be made so that the assumptions hold.

5.1 Estimation of the Best Linear Discriminant Function

Let x_1, x_2, ... x_k be the criteria of discrimination between the two groups y_1, y_2 of sizes n_1, n_2 respectively. The best linear discriminant function is

$$Y = \lambda_1 x_1 + \lambda_2 x_2 + \ldots + \lambda_k x_k, \qquad (5.1.1)$$

where λ_1, λ_2, ... , λ_k are the coefficients of the discriminant function. The mean of the first group is:

$$\overline{Y}_1 = \lambda_1 \overline{x}_{11} + \lambda_2 \overline{x}_{12} + \ldots + \lambda_k \overline{x}_{1k} , \qquad (5.1.2)$$

and the mean of the second group is:

$$\overline{Y}_2 = \lambda_1 \overline{x}_{21} + \lambda_2 \overline{x}_{22} + \ldots + \lambda_k \overline{x}_{2k} , \qquad (5.1.3)$$

$\overline{x}_{ir}$ is the mean of the <u>rth</u> measurement of the <u>ith</u> group, $i = 1,2$, $r = 1, 2, \ldots, k$. Now, the difference between the means of the first group and the second group is:

$$D = \overline{Y}_1 - \overline{Y}_2 = \lambda_1(\overline{x}_{11} - x_{21}) + \lambda_2(\overline{x}_{12} - \overline{x}_{22}) + \ldots$$

$$+ \lambda_k(\overline{x}_{1k} - \overline{x}_{2k})$$

$$= \lambda_1 d_1 + \lambda_2 d_2 + \ldots + \lambda_k d_k, \qquad (5.1.3)$$

where

$$d_r = \overline{x}_{1r} - \overline{x}_{2r} , \qquad (5.1.4)$$

$$r = 1, 2, \ldots, k .$$

The coefficients of the best linear discriminant function should be chosen to maximize the ratio:

$$R = \frac{D^2}{\sum_{i=1}^{2} \sum_{j=1}^{n_i} (Y_{ij} - \overline{Y}_i)^2} \quad . \qquad (5.1.5)$$

Define
$$S_{pq} = \sum_{i=1}^{2} \sum_{j=1}^{n_i} (x_{pij} - \overline{x}_{pi})(x_{qij} - \overline{x}_{qi}), \qquad (5.1.6)$$

$$p = 1, 2, \ldots, k, \quad q = 1, 2, \ldots, k.$$

Then

$$\sum_{i=1}^{2} \sum_{j=1}^{n_i} (Y_{ij} - \overline{Y}_i)^2 = \sum_{p=1}^{k} \sum_{q=1}^{k} \lambda_p \lambda_q S_{pq}, \qquad (5.1.7)$$

and

$$D^2 = \sum_{p=1}^{k} \sum_{q=1}^{k} \lambda_p \lambda_q d_p d_q \quad . \qquad (5.1.8)$$

Now R defined in (5.1.5) can be written as:

$$R = \frac{\sum_{p=1}^{k} \sum_{q=1}^{k} \lambda_p \lambda_q d_p d_q}{\sum_{p=1}^{k} \sum_{q=1}^{k} \lambda_p \lambda_q S_{pq}} \quad . \qquad (5.1.9)$$

To get the coefficients $\lambda_1, \lambda_2, \ldots, \lambda_k$ which maximize R, differentiate R with respect to λ's. After setting the partial derivatives equal to zero,

$$\lambda_1 S_{r1} + \lambda_2 S_{r2} + \ldots + \lambda_k S_{rk} = \frac{\lambda_1 d_1 + \lambda_2 d_2 + \ldots + \lambda_k d_k)}{R} d_r,$$

$$r = 1, 2, \ldots, k. \qquad (5.1.10)$$

Now $\{ \frac{\lambda_1 d_1 + \lambda_2 d_2 \ldots \lambda_k d_k}{R} \}$ is independent of r, and it could be considered as a constant, c. Then (5.1.10) can be written as:

$$\lambda_1 S_{r1} + \lambda_2 S_{r2} + \ldots + \lambda_k S_{rk} = c\ d_r , \qquad (5.1.11)$$

$$r = 1, 2, \ldots, k.$$

By considering c equal to one, then (5.1.11) can be written as:

$$\lambda_1 S_{r1} + \lambda_2 S_{r2} + \ldots + \lambda_k S_{rk} = d_r . \qquad (5.1.12)$$

The solution of the set (5.1.12) will be proportional to the required solution.

Let S be defined as the matrix of sums of squares and products of the k measurements, S^{-1} as the inverse of S, $\underline{\lambda}$ as the column vector of the λ's, and $\underline{d}$ as the column vector of d's. Then, the proportional solution for the λ's is:

$$\underline{\lambda} = S^{-1}\underline{d} . \qquad (5.1.13)$$

5.2 Testing the Significance of the Best Discriminant Function

Fisher [3] has shown an equivalent technique to obtain the best linear discriminant function, by letting the discriminant (y) take the two values:

$$\frac{n_2}{n_1 + n_2} \quad \text{for all individuals of the first group,}$$

and $\dfrac{-n_1}{n_1 + n_2}$ for all individuals of the second group, and determining the discriminant function as a multiple regression function of the discriminant y on the measurements $x_1, x_2, \ldots, x_k$.

Then the test of the significance of the discriminant function is the test of the significance of the multiple regression equation. The sum of squares due the discriminant y, which is equivalent to the total sum of squares, is:

$$\frac{n_1 \cdot n_2}{n_1 + n_2} \tag{5.2.1}$$

The sum of squares due regression is:

$$\left(\frac{n_1 n_2}{n_1+n_2}\right)^2 \quad D/(1 + \frac{n_1 n_2}{n_1+n_2} \; D) \; . \tag{5.2.2}$$

Then the sum of squares of residuals is the total sum of squares - sum of squares due to regression =

$$\frac{n_1 n_2}{n_1+n_2} \; [1 - \frac{n_1 n_2}{n_1+n_2} \; D/(1 + \frac{n_1 n_2}{n_1+n_2} \; D)]. \tag{5.2.3}$$

There are k degrees of freedom for regression, and (n_1+n_2-k-1) for the residual. The test statistic is

$$\frac{\text{S.S regression}/k}{\text{S.S residual}/(n_1+n_2-k-1)} \tag{5.2.4}$$

The analysis of discrimination is set up in Table (40). Table (40) gives the analysis of multiple regression of the discriminant y on the k measurements.

Table (40)

Analysis of Multiple Regression of the Discriminant y on the k Measurements

Sources	D.F	S.S	M.S	F
Regression	K	$\dfrac{\dfrac{(n_1n_2\ )^2}{n_1n_2}\ D}{1+\dfrac{n_1n_2}{n_1+n_2}\ D}$	$S.S_{Reg.}/K$	$\dfrac{M.S_{Reg.}}{M.S_{Res.}}$
Residual	n_1+n_2-k-1	$\dfrac{n_1n_2}{n_1+n_2}-S.S_{Reg.}$	$\dfrac{S.S_{Res.}}{n_1+n_2-k-1}$	
Total	n_1+n_2-1	$\dfrac{n_1n_2}{n_1+n_2}$		

5.3 Point of Classification and Probability of Misclassification

To find the point of separation between the two combinations, estimate the mean of the two, and the mid-point between the estimated means will be the point of discrimination. Thus, to classify a new observation into one of the two groups, calculate the value:

$$Y = \lambda_1 x_1 + \lambda_2 x_2 + \ldots + \lambda_k x_k \ . \qquad (5.3.1)$$

If the estimated value falls between the mid-point and one of the estimated means, then it belongs to the same group as that mean.

Since the separation point between the two groups falls midway between the two estimated means of the two groups, then an error of classification occurs when the estimated value y of the new observation is larger than the point of separation for one group and smaller for the other. Thus the probability of misclassification is:

$$\Pr\ \{|y| > \frac{D}{2}\} \quad , \quad \ldots \qquad (5.3.2)$$

where D is the distance between the estimated means of the two groups. By standardizing y, the probability of misclassification will be,

$$\Pr\ \{|z| > \frac{\overline{D}}{2}\} \ . \qquad (5.3.3)$$

5.4 Numerical Discrimination Analysis

A numerical discrimination analysis was made between the host - nematode combinations. Two combinations were taken at a time, resulting in six problems of discriminations. The criteria of discrimination were the six measurements of the larvae. For each of the six problems, a matrix of sums of squares and products, and the matrix of multipliers reciprocal to the sums of squares and products were computed. The differences between the means of the six measurements for each two combinations were computed from (5.1.4). The matrices of sums of squares and products are presented in Tables (41.a), (42.a), (43.a), (44.a), (45.a) and (46.a). The matrices of multipliers reciprocal to the sums of squares and products are presented in Tables (41.b), (42.b), (43.b), (44.b), (45.b) and (46.b). Also, for each problem the coefficients of the discriminant function were calculated from (5.1.13), and a test of significance was made for each discriminant function. The sums of squares due to regression, to residual, and to the test statistic were calculated from (5.2.2), (5.2.3) and (5.2.4) respectively. The computations of the test statistic are presented in Tables (41.c), (42.c), (43.c), (44.c), (45.c), and (46.c). Significance is indicated by an asterisk. The critical value for the test statistic under H_0 at 0.05 level is 2.0986. The test statistics were significant for each of the discriminant functions.

The estimated means of the discriminant y of each two combinations were estimated from (5.3.1) and the midway point between the two means was determined. The probability of misclassification was calculated for each function from (5.3.3).

5.4.1 Discrimination Analysis Between Horsenettle Cyst from Tobacco and Osborne Cyst from Tobacco

	Body	Stylet	Gland Orifice	Width	Tail	Tail Terminal
Body	189362.89	1078.50	1365.77	6122.00	12469.00	6858.80
Stylet	1078.50	128.10	-3.61	16.41	89.88	104.53
Gland Orifice	1365.77	-3.61	95.54	42.84	115.64	23.76
Width	6122.00	16.41	42.84	452.54	208.69	71.41
Tail	12469.00	89.88	115.64	208.69	2542.94	1413.59
Tail Terminal	6858 . 80	104.53	23.76	71.41	1413.59	2475.58

Table (41.a) Matrix of Sums of Squares and Products of Six Measurements for the Horsenettle Cyst from Tobacco and Osborne Cyst from Tobacco

	Body	Stylet	Gland Orifice	Width	Tail	Tail Terminal
Body	1565	-7059	-8111	-17596	-5409	-364
Stylet	-7059	849380	104005	54629	8604	-23795
Gland Orifice	-8111	104005	1198218	3624	-32655	25123
Width	-17596	54629	3624	435234	43433	9054
Tail	-5409	8604	-32655	43433	81834	-33044
Tail Terminal	-364	-23795	25123	9054	-33044	60773

Table (41.b) Matrix of Multipliers Reciprocal to the Sums of Squares and Products within the Horsenettle Cyst from Tobacco and Osborne Cyst from Tobacco

Note: To get true values, multiply all values by 10^{-8}.

$d_1 = 8.440$	$\lambda_1 = 0.00029350$
$d_2 = 0.112$	$\lambda_2 = -0.00016029$
$d_3 = 0.250$	$\lambda_3 = 0.00231951$
$d_4 = -1.277$	$\lambda_4 = -0.00665719$
$d_5 = 0.612$	$\lambda_5 = -0.00076408$
$d_6 = 0.550$	$\lambda_6 = 0.00002184$

The discriminant function between the Horsenettle cyst from tobacco and Osborne cyst from tobacco is,

$$Y = 0.00029350X_1 - 0.00016029X_2 + 0.00231951X_3 - 0.00665719X_4 - 0.00076408X_5 + 0.00002184X_6$$

Table (41.c) Testing the Significance of the Discriminant Function Between the Horsenettle Cyst from Tobacco and Osborne Cyst from Tobacco

Sources	D.F	S.S	M.S	F
Regression	6	22.3827	3.7031	23.6889
Residual	223	35.1173	0.1575	
Total	229	57.5		

F = 23.6889*

To classify a new observation into one of the Horsenettle cyst from Tobacco and Osborne cyst from tobacco:

The estimated mean of the Horsenettle cyst from tobacco is: 0.011864765.

The estimated mean of the Osborne cyst from tobacco is: -0.02295291

$D = 0.01108815$

$\frac{1}{2}D = 0.005544075$

The mid-point between the two estimated means is: -0.017408835.

If the estimated value of the new observation exceeds -0.017408835, it belongs to Horsenettle cyst from tobacco, or it belongs to Osborne Cyst from tobacco.

The probability of misclassification is:

$$\Pr\{|z| > 0.055424\}$$

$$= 0.4781$$

5.4.2 Discrimination Analysis Between Horsenettle Cyst from Horsenettle Weed and Osborne cyst from Horsenettle Weed

	Body	Stylet	Gland Orifice	Width	Tail	Tail Terminal
Body	231433.89	857.10	1674.27	6199.80	15949.20	7382.00
Stylet	857.10	133.46	6.84	17.74	86.85	42.44
Gland Orifice	1674.27	6.84	113.04	30.61	110.68	68.69
Width	6199.80	17.74	30.61	523.35	580.03	130.59
Tail	15949.20	86.85	110.68	580.03	3413.42	1366.68
Tail Terminal	7382.00	42.44	68.69	130.59	1366.68	2089.17

Table (42.a) Matrix of Sums of Squares and Products of Six Measurements within Horsenettle cyst from Horsenettle Weed and Osborne cyst from Horsenettle Weed

	Body	Stylet	Gland Orifice	Width	Tail	Tail Terminal
Body	868	-2522	-8120	-7099	-2166	-888
Stylet	-2522	770393	-3030	15120	-9824	-1156
Gland Orifice	-8120	-3030	997402	37086	2603	-8061
Width	-7099	15120	37086	298240	-28537	235 85
Tail	-2166	-9824	2603	-28537	55019	-26440
Tail Terminal	-888	-1156	-8061	23585	-26440	67113

Table (42.b) Matrix of Multipliers reciprocal of the Sums of Squares and Products within Horsenettle Cyst from Horsenettle Weed and Osborne Cyst from Horsenettle Weed

Note: To get true values, multiply all values by 10^{-8}.

$d_1 = 6.644$ $\lambda_1 = 0.00005705$

$d_2 = -0.117$ $\lambda_2 = -0.00126555$

$d_3 = 0.593$ $\lambda_3 = 0.00476397$

$d_4 = -0.990$ $\lambda_4 = -0.00248440$

$d_5 = -0.064$ $\lambda_5 = -0.00067610$

$d_6 = 3.050$ $\lambda_6 = 0.00172493$

The discriminant function between the Horsenettle cyst from Horsenettle weed and Osborne cyst from Horsenettle weed is:

$$Y = 0.00007507X_1 - 0.00126555X_2 + 0.00476397X_3 - 0.00248440X_4 - 0.00067610X_5 + 0.00172493X_6$$

Table (42.c) Testing the Significance of the Discriminant Function between the Horsenettle Cyst from Horsenettle Weed and Osborne Cyst from Horsenettle Weed

Sources	D.F	S.S	M.S	F
Regression	6	22.4213	3.7369	23.7564
Residual	223	35.0787	0.1573	
Total	229	57.5		

F = 23.7564*

To classify a new observation into one of the two Horsenettle cyst from Horsenettle weed and Osborne cyst from Horsenettle weed:

The estimated mean of the Horsenettle cyst from Horsenettle weed is: -0.01043540989.

The estimated mean of the Osborne cyst from Horsenettle weed is: -0.0215514165.

$D = 0.01111600666$

$\frac{D}{2} = 0.00555800333$

The mid-point between the two estimated means is: -0.0159934132.

If the estimated value of the new observation exceeds -0.0159934132, then it belongs to Horsenettle cyst from Horsenettle weed, or it belongs to Osborne Cyst from Horsenettle weed.

The probability of misclassification is:

$$\Pr\{|z| > 0.005558\}$$

$$= 0.4798$$

5.4.3 Discrimination Analysis Between the Horsenettle Cyst from Tobacco and Osborne Cyst from Horsenettle Weed

Table (43.a) Matrix of Sums of Squares and Products of the Six Measurements, within Horsenettle Cyst from Tobacco and Osborne Cyst from Horsenettle Weed

	Body	Stylet	Gland Orifice	Width	Tail	Tail Terminal
Body	197064.00	1010.10	1086.70	5933.50	13488.90	6700.80
Stylet	1010.10	78.32	1.82	26.44	89.51	60.89
Gland Orifice	1086.70	1.82	78.03	21.21	107.33	53.39
Width	5933.50	26.44	21.21	502.94	445.49	117.34
Tail	13488.90	89.51	107.33	445.49	2871.57	1288.43
Tail Terminal	6700.80	60.89	53.39	117.34	1288.43	1656.22

Table (43.b) Matrix of Multipliers Reciprocal to the Sums of Squares and Products within Horsenettle Cyst from Tobacco and Osborne cyst from Horsenettle Weed

	Body	Stylet	Gland Orifice	Width	Tail	Tail Terminal
Body	1097	-6781	-8088	-9661	-2587	-1230
Stylet	-6781	1382047	82461	15038	-6888	-21742
Gland Orifice	-8088	82461	1412970	54484	-26109	593
Width	-9661	15038	54484	320707	-20252	29813
Tail	-2587	-6888	-26109	-20252	69862	-41353
Tail Terminal	-1230	-21742	593	29813	-41343	96191

Note: To get true values, multiply all values by 10^{-8}.

d_1 =	17.773	λ_1 =	0.00022709
d_2 =	-0.035	λ_2 =	-0.00190977
d_3 =	0.565	λ_3 =	0.00573520
d_4 =	-1.200	λ_4 =	-0.00472876
d_5 =	0.539	λ_5 =	-0.00087771
d_6 =	2.158	λ_6 =	0.00128751

The discriminant function between the Horsenettle cyst from tobacco and Osborne cyst from Horsenettle weed is:

$$Y = 0.00022709X_1 - 0.00190977X_2 + 0.00573520X_3 - 0.00472876X_4 - 0.00087771X_5 + 0.00128751X_6$$

Table (43.c) Testing the Significance of the Discriminant Function Between the Horsenettle Cyst From Tobacco and the Osborne cyst from Horsenettle Weed

Sources	D.F	S.S	M.S	F
Regression	6	26.9353	4.4892	32.7656
Residual	223	30.5675	0.1370	
Total	229	57.5		

F*= 32.7656

To classify a new observation into one of the Horsenettle Cyst from tobacco and Osborne Cyst from Horsenettle Weed:

The estimated mean of the Horsenettle Cyst from tobacco is: -0.00059074.

The estimated mean of the Osborne Cyst from Horsenettle Weed is: -0.01594126.

$D = 0.0153231734l$

$\frac{1}{2}D = 0.0076665717$

The mid-point between the estimated means is: -0.0082746883.

If the estimated value of the new observation exceeds -0.0082746883, then it belongs to the Horsenettle Cyst from tobacco, or it belongs to the Osborne Cyst from HOrsenettle Weed.

The Probability of misclassification is:

$$\Pr\{|z| > 0.061893897\}$$
$$= 0.4749$$

5.4.4 Discrimination Analysis Between Horsenettle Cyst from Horsenettle Weed and Horsenettle Cyst from Tobacco

Table (44.a) Sums of Squares and Products of Measurements, within Horsenettle Cyst from Horsenettle Weed and Horsenettle Cyst from Tobacco

	Body	Stylet	Gland Orifice	Width	Tail	Tail Terminal
Body	194785.33	1284.40	1492.87	6081.50	11576.10	4653.60
Stylet	1284.40	158.74	9.34	23.94	107.90	77.11
Gland Orifice	1492.87	9.34	110.95	23.78	63.53	50.40
Width	6081.50	23.94	23.78	506.63	297.86	-34.55
Tail	11576.10	107.90	63.53	297.86	2741.67	982.65
Tail Terminal	4653.60	77.11	50.40	-34.55	982.65	2055.85

Table (44.b) Matrix of Multipliers Reciprocal to the Sums of Squares and Products within Horsenettle Cyst from Horsenettle Weed and Horsenettle Cyst from Tobacco

	Body	Stylet	Gland Orifice	Width	Tail	Tail Terminal
Body	1209	-4773	-11094	-12104	-2962	-1075
Stylet	-4773	673174	10057	27369	-5366	-11667
Gland Orifice	-11094	10057	1027408	73786	17305	-7484
Width	-12104	27369	73786	339551	702	29934
Tail	-2962	-5366	17305	702	55975	-20262
Tail Terminal	-1075	-11667	-7484	29934	-20262	61883

Note: To get true values, multiply all values by 10^{-8}.

$d_1 = -11.129$ $\lambda_1 = -0.00018678$

$d_2 = -0.082$ $\lambda_2 = -0.00009544$

$d_3 = 0.029$ $\lambda_3 = 0.00171434$

$d_4 = 0.210$ $\lambda_4 = 0.00232847$

$d_5 = 0.608$ $\lambda_5 = 0.00050009$

$d_6 = 0.891$ $\lambda_6 = 0.00061816$

The discriminant function between the Horsenettle cyst from Horsenettle weed and Horsenettle cyst from tobacco is:

$$Y = -0.00018678X_1 - 0.00009544X_2 + 0.00171434X_3 + 0.00232847X_4 + 0.0050009X_5 + 0.00061816X_6$$

Table (44.c) Testing the Significance of the Discriminant Function Between the Horsenettle Cyst from Horsenettle Weed and Horsenettle Cyst from Tobacco

Sources	D.F	S.S	M.S	F
Regression	6	9.5839	1.5973	7.4339
Residual	223	47.9161	0.2149	
Total	229	57.5		

F = 7.4339*

To classify a new observation into one of the Horsenettle cyst from Horsenettle weed and Horsenettle cyst from tobacco:

The estimated mean of the Horsenettle cyst from Horsenettle weed is: 0.003634515573.

The estimated mean of the Horsenettle cyst from tobacco is: 0.000155998149

$$D = 0.003478517424 55$$

$$\frac{D}{2} = 0.00173925871227$$

The mid-point between the two estimated means is: 0.001895256861.

If the estimated value of the new observation exceeds the 0.001895256861, then it belongs to the Horsenettle cyst from Horsenettle weed, or it belongs to the Horsenettle cyst from tobacco.

The probability of misclassification is:

$$\Pr\{|z| > 0.0295356\}$$
$$= .4880$$

5.4.5 Discrimination Analysis Between the Osborne Cyst From Horsenettle Weed and Osborne Cyst from Tobacco

Table (45.a) Matrix of Sums of Squares and Products of Six Measurements, within Osborne Cyst from Horsenettle Weed and Osborne Cyst from Tobacco

	Body	Stylet	Gland Orifice	Width	Tail	Tail Terminal
Body	226038.45	651.20	1547.17	6240.30	16842.10	9587.20
Stylet	651.20	102.82	-6.11	10.21	68.83	69.86
Gland Orifice	1547.17	-6.11	97.63	49.67	162.79	42.05
Width	6240.30	10.21	49.67	469.26	490.86	236.55
Tail	16842.10	68.83	162.79	490.86	3214.69	1797.62
Tail Terminal	9587.20	69.86	42.05	236.55	1797.62	2508.90

Table (45.b) Matrix of Multipliers Reciprocal to the Sums of Squares and Products within Osborne Cyst from Horsenettle Weed and Osborne Cyst from Tobacco

	Body	Stylet	Gland Orifice	Width	Tail	Tail Terminal
Body	1003	-3317	-5898	-9005	-3250	-463
Stylet	-3317	1012631	119275	22556	-4674	-16299
Gland Orifice	-5898	119275	1202339	-17141	-50558	36908
Width	-9005	22556	-17141	339308	-9025	8545
Tail	-3250	-4674	-50558	-9025	73755	-38599
Tail Terminal	-463	-16299	36908	8545	-38599	68313

Note: To get true values, multiply all values by 10^{-8}.

$d_1 = -9.333$ $\lambda_1 = -0.00006774$

$d_2 = 0.147$ $\lambda_2 = 0.00166397$

$d_3 = -0.315$ $\lambda_3 = -0.00367623$

$d_4 = -0.077$ $\lambda_4 = 0.00052278$

$d_5 = 0.068$ $\lambda_5 = 0.00113348$

$d_6 = -1.608$ $\lambda_6 = -0.00122831$

The discriminant function between the Osborne Cyst from Horsenettle Weed and Osborne Cyst from tobacco is:

$$Y = -0.00006774X_1 + 0.00166397X_2 - 0.00367623X_3 + 0.00052278X_4 + 0.00113348X_5 - 0.00122831X_6$$

Table (45.c) Testing the Significance of the Discriminant Function Between the Osborne Cyst from HOrsenettle Weed and Osborne Cyst from Tobacco

Sources	D.F	S.S	M.S	F
Regression	6	10.8540	1.8090	8.6481
Residual	223	46.6460	0.2092	
Total	229	57.5		

F = 8.6481*

To classify a new observation into one of the Osborne Cyst from Horsenettle Weed, and Osborne Cyst from tobacco:

The estimated mean of Osborne Cyst from Horsenettle Weed is: 0.02457.

The estimated mean of the Osborne Cyst from tobacco is: 0.020522.

$$D = 0.00404677852$$

$$\frac{D}{2} = 0.00202338926$$

The mid-point between the two estimated means is: 0.022534941.

If the estimated value of new observation exceeds 0.022534941, then it belongs to the Osborne Cyst from Horsenettle Weed, or it belongs to Osborne Cyst from Tobacco.

The probability of misclassification:

$$\Pr\{|z| > 0.031807\}$$

$$= 0.4868$$

5.4.6 Discrimination Analysis Between the Horsenettle Cyst from Horsenettle Weed and Osborne Cyst from Tobacco

Table (46.a) Matrix of Sums of Squares and Products of Six Measurements, within Horsenettle Cyst from Horsenettle Weed and Osborne Cyst from Tobacco

	Body	Stylet	Gland Orifice	Width	Tail	Tail Terminal
Body	223732.78	925.50	1953.34	6388.30	14929.30	7540.00
Stylet	925.50	183.24	1.41	7.71	87.22	86.08
Gland Orifice	1953.34	1.41	130.55	52.24	118.99	39.06
Width	6388.30	7.71	52.24	472.95	343.23	84.66
Tail	14929.30	87.22	118.99	343.23	3084.79	1491.84
Tail Terminal	7540.00	86.08	39.06	84.66	1491.84	2908.53

Table (46.b) Matrix of Multipliers Reciprocal to the Sums of Squares and Products within Horsenettle Cyst from Horsenettle Weed and Osborne Cyst from Tobacco

	Body	Stylet	Gland Orifice	Width	Tail	Tail Terminal
Body	1106	-3155	-8710	-11369	-3374	-595
Stylet	-3155	564947	31890	32271	-977	-9409
Gland Orifice	-8710	31890	885653	17037	959	8753
Width	-11369	32271	17037	354930	7015	14359
Tail	-3374	-977	959	7015	58273	-21330
Tail Terminal	-595	-9409	8753	14359	-21330	46607

Note: To get true values, multiply all values by 10^{-8}.

$d_1 = -2.689$ $\lambda_1 = 0.00005784$

$d_2 = 0.030$ $\lambda_2 = -0.00013739$

$d_3 = 0.278$ $\lambda_3 = 0.00265019$

$d_4 = -1.068$ $\lambda_4 = -0.00322063$

$d_5 = 0.003$ $\lambda_5 = -0.00028765$

$d_6 = 1.442$ $\lambda_6 = 0.00055559$

The discriminant function between the Horsenettle Cyst from Horsenettle Weed and Osborne Cyst from tobacco is:

$$Y = 0.00005784X_1 - 0.00013739X_2 + 0.00265019X_3$$
$$- 0.00322063X_4 - 0.00028765X_5 + 0.00055559X_6$$

Table (46.c) Testing the Significance of the Discriminant Function Between the Horsenettle Cyst from Horsenettle Weed and Osborne Cyst from Tobacoo

Sources	D.F	S.S	M.S	F
Regression	6	12.4719	2.0786	10.2944
Residual	223	45.0281	0.2019	
Total	229	57.5		

F = 10.2944*

To classify a new observation into one of Horsenettle Cyst from Horsenettle Weed and Osborne Cyst from tobacco:

The estimated mean of the Horsenettle Cyst from Horsenettle Weed is: -0.02336287.

The estimated mean of the Osborne Cyst from tobacco is: -0.02818017.

$$D = 0.00481703003$$

$$\frac{D}{2} = 0.00240851501$$

The mid-point between the two estimated means is: -0.025771385.

If the estimated value of the new observation exceeds -0.025771385, then it belongs to the Horsenettle Cyst from Horsenettle Weed, or it belongs to Osborne Cyst from tobacco.

The probability of misclassification is:

$$\Pr\{|z| > 0.034703\}$$

$$= 0.4860$$

Chapter VI

NONPARAMETRIC TEST PROCEDURE

Results in Chapter II showed that all the host - nematode combinations for stylet length and the gland orifice length for the Horsenettle cyst on both hosts were not normally distributed. In Chapter III, it was considered that the variances of host - nematode combinations for the tail terminal were unequal. Thus, with these results, it was decided to test the differences among the means of the host - nematode combinations for each of stylet length, gland orifice length, and tail terminal length by a nonparametric test procedure, which requires no assumptions of normality and homogeneity of variances.

This chapter will be divided into two sections. In the first section, the Kruskal-Wallis one-way analysis of variances by ranks will be described; in the second section, numerical results of the Kruskal-Wallis test for the measurements, stylet length, gland orifice length, and tail terminal length will be given.

6.1 Kruskal-Wallis One-Way Analysis of Variance by Ranks Function (H-Test)

Suppose that there are k independent samples from continuous distributions, and the sample sizes are n_1, n_2,...,n_k,

$\sum_{i=1}^{k} n_i = N.$

To test the hypothesis, H_0: the samples are from identical distributions, against H_a: the samples are from different distributions, the Kruskal-Wallis test will be used. The technique of this test is to arrange the N observations into an ordered series and rank them from (1) for the smallest observation, up to (N) for the largest one. In the case of ties, each observation in a tie group will receive the value of the mid point between the lowest rank and the highest rank in the tie group, using ranks as if ties were not allowed.

If the samples were from identical distributions, one expects the sum of ranks of all observations will be divided among the samples in proportion to the sample sizes, and there is a reason to reject H_0 if the sum of ranks is significantly divided disproportionately. The test statistic was defined [10] in 1952 by W. H. Kruskal and W. A. Wallis as

$$H = \left[\frac{12}{N(N+1)} \right] \left[\sum_{i=1}^{k} \frac{R_i^2}{n_i} \right] - 3(N+1), \qquad (6.1.1)$$

where R_i is the sum of ranks of all observations of the ith sample. H_0 will be rejected for large values of H.

In the case when the tied observations make up more than 20% of all observations, the value of the test statistic will decrease, and the computed value of H should be divided by a correction factor,

$$c = 1 - \frac{\sum_{j=1}^{m} T_j}{N^3 - N} , \qquad (6.1.2)$$

where $T_j = t_j^3 - t_j$, and t_j is the number of the tie observations in the jth group.

$$\text{Corrected } H = \frac{H}{c} . \qquad (6.1.3)$$

Under H_0, the critical values of the test statistic, for k=3 and $n_i \leq 5$, i = 1,2,3, were tabulated in [10] for the probability levels 0.01, 0.05, and 0.1.

Under H_0 for k=3 and one sample of size exceeding 5, or for k > 3, the test statistic is distributed approximately as χ^2 with degrees of freedom equal to k-1. H_0 is to be rejected for large values of χ^2 with k-1 degrees of freedom.

6.2 Numerical Results

In this section, the host - nematode combinations of the measurements, stylet length, gland orifice length, and tail terminal length, were considered as independent samples. For each measurement, all observations were ranked from 1 to 460. The sums of ranks, the percentages, the values of the test statistics from (6.1.1), the values of the correction factor from (6.1.2) in the cases of need, and the corrected test statistic from (6.1.3), all were computed. The test statistic has a ^{2} distribution with 3 degrees of freedom, and the critical value for the test statistic at the 0.05 probability level is 7.81. The test statistic was significant for the measurements, gland orifice length and the tail terminal length. The computations of the test statistics follow:

(1) Stylet length:

Sums of Ranks

Horsenettle cyst from Horsenettle weed = 25785.0

Horsenettle cyst from tobacco = 27079.5

Osborne cyst from Horsenettle weed = 27821.0

Osborne cyst from tobacco = 25344.5

Percentage of ties = 93.9%

$H = 1.93237$

$c = 0.63585$

Corrected $H = 3.03901$

(2) Gland Orifice length:

Sums of Ranks

Horsenettle cyst from Horsenettle weed = 31683.5

Horsenettle cyst from tobacco = 30915.5

Osborne cyst from Horsenettle weed = 18437.0

Osborne cyst from tobacco = 24994.0

Percentage of ties = 92.2%

H = 55.92105

c = 0.59052

Corrected H = 94.69762*

(3) Tail Terminal length:

Sums of Ranks

Horsenettle cyst from Horsenettle weed = 32327.5

Horsenettle cyst from tobacco = 28984.5

Osborne cyst from Horsenettle weed = 18842.0

Osborne cyst from tobacco = 25876.0

Percentage of ties = 77.4%

H = 48.79666

c = 0.99483

Corrected H = 49.05052*

Chapter VII

SUMMARY

By the nature of the data, this study was limited to a two-way factorial experiment with fixed effects, because it was of interest to investigate whether or not there were significant effects between the two nematodes, and between the two hosts with respect to the six measurements of the host - nematode combinations.

The measurements of body length, width, and tail terminal length were considered to be distributed normally with common variance after making appropriate tests.

The conclusions drawn from the analyses of the data:

(1) There is no significant interaction effect between the host and nematodes for any of the measurements.

(2) The tobacco host mean was significantly larger than the Horsenettle host mean for body length.

(3) The Horsenettle cyst mean was significantly larger than the Osborne cyst mean for body length.

(4) The Osborne cyst mean was significantly larger than the Horsenettle cyst mean for width.

(5) There are no significant differences among the host - nematode combinations for stylet length.

(6) There are significant differences among the host - nematode combinations for gland orifice, and tail terminal lengths.

Between any two of the four host - nematode combinations, there is a significant discrimination function based on the six measurements, with probability of misclassification of 50%. So for every 100 observations to be classified into one of any two combinations, one expects 50 observations to be wrongly classified.

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Thanks is given to   for her last minute typing assistance.

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APPENDIX

TABLE (1 - A) The Observed Values for the Body Length, of the Host - Nematode Combinations.

Horsnettle Cyst from Horsnettle Weed	Horsenettle Cyst from Tobacco	Osborne Cyst from Horsenettle Weed	Osborne Cyst from Tobacco
491.4	518.0	532.8	451.4
529.8	518.0	552.0	466.2
516.5	518.0	562.4	491.4
489.9	481.0	488.4	444.0
445.5	485.4	481.0	488.4
463.2	532.8	518.0	518.0
458.8	547.6	525.0	478.0
532.8	506.2	495.8	451.4
526.9	473.6	569.8	503.2
488.4	510.6	518.0	458.5
473.6	475.1	503.2	518.0
532.8	518.0	516.5	547.6
532.8	525.4	540.2	448.4
478.0	495.8	518.0	466.2
500.2	481.0	577.2	540.2
522.4	463.2	488.0	495.8
503.2	525.4	540.2	525.4
516.5	472.1	458.8	473.6
503.2	495.8	529.8	472.1
503.2	547.6	510.6	495.8
489.9	532.8	515.0	525.4
521.0	532.8	458.8	532.8
503.2	525.4	500.2	495.8
535.8	518.0	540.2	547.6
488.4	473.6	440.0	495.8
489.9	547.6	466.2	518.0
495.8	547.6	518.0	547.6
473.6	518.0	532.8	495.8
478.0	510.6	518.0	461.8
509.1	525.4	495.8	488.4
484.0	495.8	521.0	495.8
518.0	495.8	488.4	458.8
489.9	458.8	458.8	492.8
488.0	518.0	473.6	492.8
515.0	540.2	441.0	532.8
500.2	510.6	481.0	547.6
503.2	495.8	488.4	547.6
437.8	503.2	451.4	489.9
503.2	559.4	458.8	555.0
512.1	532.8	503.2	518.0

TABLE (1 - A) Continued

Horsenettle Cyst from Horsenettle Weed	Horsenettle Cyst from Tobacco	Osborne Cyst from Horsenettle Weed	Osborne Cyst from Tobacco
515.0	519.5	510.6	485.4
532.8	510.6	555.0	495.8
525.4	519.5	503.2	518.0
503.2	495.8	547.6	540.2
482.5	488.4	492.8	532.8
504.7	481.0	532.8	503.2
504.7	495.8	495.8	532.8
501.7	488.4	504.7	488.4
455.8	481.0	503.2	503.2
418.8	488.4	458.8	540.2
461.8	510.6	466.2	470.6
464.7	529.8	518.0	492.8
481.0	491.4	500.2	444.0
485.4	488.4	481.0	500.2
532.8	510.6	503.2	503.2
481.0	525.4	518.0	525.4
473.6	503.2	495.8	444.0
441.0	525.4	436.6	532.8
481.0	547.6	510.6	510.6
525.4	500.2	515.0	506.2
503.2	547.6	481.0	510.6
458.8	577.2	444.0	532.8
488.4	519.5	495.8	525.4
473.6	540.2	461.8	444.0
495.8	518.0	510.6	458.8
577.2	529.8	495.8	547.6
475.1	562.4	488.4	532.8
577.2	495.8	503.2	532.8
488.4	503.2	503.2	518.0
525.4	518.0	473.6	485.0
525.4	473.6	458.8	518.0
525.4	503.2	436.6	458.8
547.6	510.6	529.8	466.2
525.4	510.6	473.6	503.2
510.6	481.0	503.2	547.6
540.2	473.6	478.0	516.5
473.6	481.0	488.4	503.2
518.0	488.4	481.0	495.8
500.2	510.6	444.0	504.7
550.6	550.7	444.0	475.1

TABLE (1 - A) Continued

Horsenettle Cyst from Horsenettle Weed	Horsenettle Cyst from Tobacco	Osborne Cyst from Horsenettle Weed	Osborne Cyst from Tobacco
590.5	540.2	481.0	525.4
510.6	555.0	507.6	466.2
488.4	466.2	488.4	532.8
488.4	495.8	495.8	510.6
473.6	495.8	488.4	518.0
518.0	555.0	488.4	525.4
473.6	503.2	436.6	569.8
510.6	532.8	488.4	562.4
562.4	488.4	532.8	569.8
510.6	510.6	473.6	525.4
540.2	577.2	523.9	537.2
476.6	550.7	518.0	525.4
547.6	518.0	473.6	491.4
503.2	510.6	515.0	451.4
458.8	532.8	532.8	485.4
510.6	540.2	525.4	510.6
532.8	547.6	529.8	498.8
521.0	525.4	532.8	547.6
515.0	532.8	518.0	547.6
488.4	510.6	525.4	481.0
486.9	488.4	515.0	466.2
436.6	510.6	481.0	532.8
503.2	518.0	532.8	555.0
518.0	481.0	515.0	481.0
481.0	519.5	503.2	515.0
518.0	466.2	510.6	503.2
540.2	525.4	495.8	525.4
547.6	547.6	518.0	518.0
592.0	540.2	444.0	481.0
547.6	540.2	473.6	532.8
451.4	555.0	429.2	532.8
532.8	540.2	481.0	532.8
503.2	540.2	451.0	500.2
547.6	547.6	414.4	525.4
495.8	562.4	495.8	525.4

TABLE (2 - A) The Observed Values of Stylet Length, of the Host - Nematode Combinations.

Horsenettle Cyst from Horsenettle Weed	Horsenettle Cyst from Tobacco	Osborne Cyst from Horsenettle Weed	Osborne Cyst from Tobacco
24.0	24.0	23.2	24.0
25.6	24.0	24.0	24.0
24.0	24.0	24.0	24.0
24.0	24.0	24.0	20.8
24.0	22.4	24.0	24.0
24.0	24.0	24.0	24.0
22.6	24.0	23.2	24.0
24.3	22.7	24.0	24.0
24.2	22.4	24.0	24.0
24.5	24.0	24.0	24.0
24.0	24.0	24.0	24.0
26.4	24.0	24.0	24.0
24.0	24.0	24.0	24.0
23.2	24.0	24.0	24.0
24.0	24.0	24.0	24.0
22.9	23.2	24.0	22.4
24.0	24.0	24.0	24.0
24.0	23.2	24.0	24.0
23.7	24.8	24.0	24.0
24.0	24.8	24.0	24.0
24.0	24.0	22.4	24.0
24.2	25.6	24.0	22.4
24.0	24.0	24.0	24.0
24.0	24.0	24.0	22.7
24.0	24.0	24.0	22.4
22.4	24.0	24.3	24.0
23.2	24.0	24.0	22.4
28.3	24.0	24.0	22.4
22.7	25.6	24.0	24.0
24.0	24.8	24.0	24.0
23.8	24.0	24.8	24.0
23.2	24.0	24.0	24.0
24.0	24.0	24.0	24.0
24.2	24.0	24.0	24.0
24.0	24.0	24.0	22.4
24.0	24.0	24.0	24.0
23.7	24.0	24.0	23.7
24.3	24.0	23.2	24.0
25.6	24.0	24.0	24.0
24.0	24.0	24.0	23.2

TABLE (2 - A) Continued

Horsenettle Cyst from Horsenettle Weed	Horsenettle Cyst from Tobacco	Osborne Cyst from Horsenettle Weed	Osborne Cyst from Tobacco
23.8	24.0	24.0	22.4
22.9	24.0	24.0	22.4
24.0	24.0	24.0	22.4
22.4	24.0	24.0	23.2
23.7	23.2	24.0	24.0
24.0	24.0	24.0	24.0
24.0	24.0	24.0	24.0
24.0	24.0	24.0	22.4
24.0	24.0	24.0	23.2
24.2	23.2	24.0	22.9
24.0	24.0	23.2	24.0
24.0	24.0	24.0	22.4
22.4	23.2	24.0	24.0
23.2	23.2	24.0	24.0
24.0	23.2	24.0	24.0
24.0	24.0	24.0	24.0
24.0	22.4	24.0	28.0
20.8	23.2	23.2	24.0
22.4	25.6	24.0	24.0
22.4	24.0	24.0	24.0
24.0	24.0	24.0	24.0
23.2	24.0	23.2	24.0
24.0	24.0	23.2	24.0
24.0	25.6	24.0	20.8
24.0	24.0	24.0	24.0
24.0	24.0	24.0	24.0
24.0	24.0	24.0	24.0
24.0	24.0	24.0	24.0
22.4	22.4	24.0	24.0
23.2	24.0	24.0	22.4
21.3	24.0	23.2	24.0
24.0	24.0	24.0	24.0
24.0	24.0	24.0	24.0
24.0	23.2	24.0	24.0
24.0	24.0	24.0	24.0
24.0	22.4	23.2	23.2
23.2	22.4	24.0	24.0
24.0	22.4	24.0	24.0
23.2	24.0	24.0	24.0
24.0	24.0	24.0	22.4

TABLE (2 - A) Continued

Horsenettle Cyst from Horsenettle Weed	Horsenettle Cyst from Tobacco	Osborne Cyst from Horsenettle Weed	Osborne Cyst from Tobacco
25.6	24.0	24.0	22.7
24.0	24.8	24.8	24.0
24.0	23.2	24.0	24.0
24.0	24.0	22.4	24.0
24.0	24.0	24.0	24.0
24.0	24.0	24.0	24.0
23.2	24.0	22.4	25.6
23.2	24.0	24.0	24.0
24.0	22.4	22.4	24.0
19.2	22.4	22.4	24.2
24.0	24.0	23.2	24.0
24.0	24.0	24.0	24.0
24.0	24.0	24.0	24.0
24.0	24.0	24.0	24.0
24.0	24.0	24.0	24.0
24.0	24.0	24.0	24.0
24.0	24.0	24.0	22.4
24.0	24.0	24.0	24.0
24.0	24.8	24.0	24.0
22.4	24.0	24.0	24.0
24.0	24.0	24.0	24.0
22.4	24.0	24.0	24.0
24.0	24.0	22.4	24.0
24.0	24.0	24.0	23.2
24.0	24.0	24.0	24.0
22.4	22.4	24.0	24.0
24.0	22.4	23.2	24.0
24.0	24.0	24.0	24.0
24.0	23.2	24.0	24.0
24.0	24.0	24.0	24.0
22.4	22.4	24.0	23.2
22.4	22.4	25.6	24.0
23.2	24.0	22.4	24.0
24.0	24.0	24.0	22.4
24.0	24.0	24.0	24.0

TABLE (3 - A) The Observed Values of the Gland Orifice Length, of the Host - Nematode Combinations.

Horsenettle Cyst from Horsenettle Weed	Horsenettle Cyst from Tobacco	Osborne Cyst from Horsenettle Weed	Osborne Cyst from Tobacco
5.0	6.4	5.0	6.1
7.2	6.4	4.8	5.6
7.4	6.4	6.4	5.6
6.4	6.7	5.6	5.6
6.6	6.4	5.3	5.6
5.6	6.4	5.6	7.2
6.1	6.4	6.4	4.8
6.1	6.1	4.8	4.8
6.4	5.6	6.4	6.4
6.4	5.3	5.6	5.6
4.8	5.3	5.1	7.2
6.4	5.1	4.8	6.4
6.7	5.6	5.6	5.6
6.1	6.4	6.1	4.8
6.6	5.6	6.4	7.2
6.2	6.2	4.8	6.4
6.1	4.8	5.0	6.4
6.4	5.6	5.6	4.8
6.4	6.4	5.6	4.8
6.1	5.6	5.6	6.4
6.4	6.6	5.0	6.1
6.4	6.4	4.8	8.0
6.6	5.6	5.0	6.4
7.2	6.4	5.6	6.4
5.1	6.4	6.1	5.6
6.4	6.1	5.3	6.4
6.4	6.4	5.3	6.4
6.4	6.6	6.4	6.4
6.4	6.4	5.6	5.6
6.4	5.9	6.4	6.1
6.1	6.2	6.4	6.4
6.1	6.4	6.4	4.8
6.1	6.4	4.8	6.4
7.7	6.4	6.4	6.4
6.4	5.1	5.6	6.4
5.6	5.6	5.1	6.4
5.6	6.4	4.8	7.2
6.7	5.3	5.1	6.4
4.6	5.0	5.6	6.1
6.2	7.2	5.3	6.4

TABLE (3 - A) Continued

Horsenettle Cyst from Horsenettle Weed	Horsenettle Cyst from Tobacco	Osborne Cyst from Horsenettle Weed	Osborne Cyst from Tobacco
6.4	6.2	5.6	6.4
5.9	5.6	6.4	6.4
5.0	6.4	5.6	6.4
6.1	5.6	7.2	7.2
6.2	4.8	4.8	6.4
5.9	6.4	4.8	6.4
5.6	6.1	6.4	6.1
7.7	5.0	5.6	5.6
4.5	5.6	4.8	6.4
4.0	5.6	4.8	7.2
4.2	6.4	5.6	6.4
3.2	6.4	5.6	6.4
4.8	5.9	5.0	6.4
6.4	5.6	4.8	6.4
6.7	5.1	5.0	6.4
6.4	6.4	5.6	6.1
6.4	4.8	5.6	4.8
6.4	6.4	5.6	6.1
6.4	5.9	6.1	4.8
6.4	4.8	4.8	5.1
6.4	6.4	5.0	5.6
4.8	7.2	5.3	6.1
6.4	6.2	4.8	6.4
5.6	6.1	5.6	4.8
6.4	6.1	5.6	4.8
6.4	6.4	5.0	4.8
6.6	6.4	4.8	6.1
5.6	4.8	5.6	5.6
4.8	6.4	6.1	5.6
5.6	5.6	6.1	4.8
6.4	5.1	6.1	6.1
6.4	6.1	5.1	4.8
6.4	5.6	5.1	5.6
6.4	4.8	4.8	5.6
6.4	6.4	4.8	6.6
6.1	5.2	4.8	5.0
4.8	6.8	4.8	5.0
6.4	7.2	4.8	5.3
6.1	6.4	4.8	6.2
6.4	6.2	4.8	4.8

TABLE (3 - A) Continued

Horsenettle Cyst from Horsenettle Weed	Horsenettle Cyst from Tobacco	Osborne Cyst from Horsenettle Weed	Osborne Cyst from Tobacco
7.2	6.4	5.6	5.6
6.1	6.4	5.6	4.8
6.4	5.6	6.2	4.8
6.4	6.4	5.6	5.1
6.4	6.4	5.6	5.6
5.6	6.1	4.8	5.6
5.3	6.4	4.8	6.4
6.1	6.4	5.1	5.6
6.4	5.3	5.6	5.3
6.4	5.6	5.6	5.3
8.8	6.4	5.6	5.3
5.6	6.4	6.4	5.3
6.7	5.6	5.6	6.1
6.9	6.1	5.1	4.8
4.8	6.4	5.3	5.6
6.4	6.4	6.2	6.4
6.4	6.4	6.4	5.6
7.2	6.1	5.6	5.6
6.1	6.4	5.6	5.6
6.4	6.4	4.8	4.8
6.1	6.4	4.8	5.6
4.8	7.2	6.4	5.2
5.6	6.4	6.4	5.6
7.2	5.6	5.3	5.0
5.6	6.2	5.6	6.1
6.4	5.6	6.4	4.8
5.6	7.2	6.1	5.6
4.8	6.2	5.6	5.3
6.4	7.2	6.4	5.6
4.8	6.2	6.7	4.8
5.6	6.4	4.5	5.0
6.7	6.4	4.8	5.6
4.8	5.6	5.6	4.8
6.1	5.6	4.8	6.1
6.4	6.4	5.6	6.4

TABLE (4 - A) The Observed Values Width for the Host - Nematode Combinations.

Horsenettle Cyst from Horsenettle Weed	Horsenettle Cyst from Tobacco	Osborne Cyst from Horsenettle Weed	Osborne Cyst from Tobacco
19.7	20.8	23.2	18.4
20.8	20.0	24.8	20.0
20.8	21.6	23.7	20.8
20.2	18.4	21.0	20.8
19.0	19.2	22.4	20.0
19.2	19.2	20.8	22.4
19.2	20.0	21.6	18.4
20.8	20.5	21.6	19.2
20.8	18.9	24.8	22.4
19.5	19.4	22.4	20.8
19.7	17.9	23.2	20.8
21.1	19.2	24.8	24.0
20.8	19.2	22.8	17.6
20.6	19.2	22.4	18.4
20.8	18.4	23.2	23.2
21.9	19.0	22.4	22.7
21.6	20.3	23.2	22.4
20.0	19.2	21.6	19.2
20.3	20.0	21.6	20.0
20.8	24.0	20.8	20.8
19.4	20.0	22.1	23.2
20.8	19.2	21.0	22.4
20.8	19.2	22.6	20.8
21.6	20.0	20.6	22.4
19.7	21.6	21.6	23.2
20.2	22.4	21.1	22.1
19.5	21.6	22.4	22.6
19.2	21.6	21.6	20.5
20.8	22.4	22.9	22.2
21.0	19.2	21.6	20.8
22.2	18.4	22.6	20.8
20.3	19.0	22.4	20.0
21.0	18.4	18.4	20.0
20.8	20.6	19.2	20.8
20.0	22.4	19.2	22.4
20.6	21.1	20.5	20.8
20.5	20.6	20.8	24.0
20.6	22.4	20.5	20.0
19.2	20.8	20.0	23.7
20.8	20.8	20.2	24.8

TABLE (4 - A) Continued

Horsenettle Cyst from Horsenettle Weed	Horsenettle Cyst from Tobacco	Osborne Cyst from Horsenettle Weed	Osborne Cyst from Tobacco
20.0	20.8	23.2	20.5
20.8	21.3	23.7	22.4
19.4	20.8	20.8	23.2
20.8	21.6	23.7	23.7
20.5	19.0	23.7	22.4
19.0	19.4	22.4	20.8
20.8	17.9	22.1	22.4
19.0	19.2	21.6	21.0
21.3	19.0	22.1	20.8
20.6	18.4	20.8	22.4
20.8	19.0	20.8	20.8
20.6	20.0	21.6	19.5
17.6	18.4	22.1	21.6
20.0	19.0	21.3	22.1
20.5	21.9	20.8	21.3
19.2	20.5	21.6	22.1
18.4	22.4	22.4	21.6
19.4	20.8	22.2	22.4
20.0	21.9	21.9	21.6
20.8	21.4	22.6	22.1
20.0	22.2	24.0	22.4
17.6	22.4	20.6	23.2
17.6	20.8	20.8	23.2
18.4	21.9	20.0	22.4
20.0	22.7	20.8	20.0
22.4	20.8	20.5	22.2
18.9	21.3	21.1	22.7
24.0	19.2	22.4	22.1
17.6	19.0	21.1	22.1
21.6	19.2	19.2	19.7
22.4	19.2	19.2	20.8
18.4	19.2	17.9	19.7
22.4	20.5	20.0	21.0
22.4	20.5	18.4	20.6
20.0	18.4	19.2	21.0
20.8	18.4	18.4	20.8
17.6	18.4	20.0	21.6
23.2	21.6	20.8	21.0
19.2	20.0	16.4	21.6
22.1	20.0	18.4	20.0

TABLE (4 - A) Continued

Horsenettle Cyst from Horsenettle Weed	Horsenettle Cyst from Tobacco	Osborne Cyst from Horsenettle Weed	Osborne Cyst from Tobacco
24.4	20.0	19.6	21.6
19.7	21.6	20.0	21.2
20.0	18.4	19.2	21.9
19.2	18.7	22.7	21.6
18.4	18.4	20.0	20.8
20.8	21.9	21.6	23.2
18.4	19.2	21.6	22.4
19.0	20.8	22.4	23.2
20.8	19.2	23.2	24.0
24.0	20.8	20.5	22.2
21.6	24.0	22.9	24.8
18.4	21.6	22.1	23.7
22.4	21.6	21.6	22.1
19.2	20.0	22.4	21.6
24.0	20.8	22.2	20.8
20.0	20.0	22.4	21.3
21.6	20.0	21.6	20.8
21.3	18.9	20.8	22.4
19.2	20.0	22.1	22.4
19.2	19.2	21.6	20.8
18.4	19.2	22.1	19.2
18.4	19.2	21.3	22.4
19.4	18.4	20.8	22.7
20.8	18.1	22.4	20.8
20.8	19.2	20.8	22.4
22.1	18.4	20.8	20.8
22.4	19.5	20.8	21.6
23.2	20.5	21.6	21.3
23.2	22.1	22.4	20.8
23.2	22.4	21.6	21.6
18.4	23.4	21.6	22.4
22.4	22.6	24.0	21.6
21.6	22.7	20.5	21.6
24.0	21.6	19.2	20.0
21.6	23.2	23.5	22.4

TABLE (5 - A) The Observed Values of the Tail Length for the Host - Nematode Combinations.

Horsnettle Cyst from Horsenettle Weed	Horsenettle Cyst from Tobacco	Osborne Cyst from Horsenettle Weed	Osborne Cyst from Tobacco
48.2	48.8	51.2	50.4
52.0	50.4	54.4	49.6
52.8	49.6	57.6	49.6
46.4	51.4	52.8	43.2
48.2	52.0	52.8	48.8
49.6	55.2	50.4	48.8
44.9	54.6	53.6	54.4
53.3	48.0	48.0	49.6
52.8	50.4	60.0	54.4
51.2	48.0	51.2	45.6
47.8	52.8	51.2	51.2
52.9	50.4	46.4	52.8
52.6	53.6	52.8	44.0
44.8	50.4	52.0	51.2
47.8	49.6	59.2	52.8
55.8	48.0	43.2	51.2
52.8	62.4	56.0	52.8
52.6	45.6	49.6	47.2
49.6	52.0	54.4	47.2
49.8	56.0	52.8	51.2
48.3	48.0	50.4	54.4
55.2	51.2	47.2	53.6
52.8	51.2	46.4	51.2
51.2	50.4	52.0	52.8
48.0	44.8	46.4	51.2
53.6	46.4	46.4	53.6
49.8	53.1	55.2	52.8
51.4	49.6	53.6	52.0
49.6	49.6	47.2	50.4
53.3	56.0	48.0	48.8
49.4	49.6	57.6	51.2
51.0	54.4	46.4	47.2
49.8	45.6	45.6	49.6
47.8	51.2	48.8	48.0
51.7	51.2	49.6	48.8
52.5	52.8	48.0	51.2
52.8	52.0	48.5	51.2
51.2	49.6	48.0	51.2
51.5	54.4	47.2	54.4
52.8	50.4	50.4	49.6

TABLE (5 - A) Continued

Horsenettle Cyst from Horsenettle Weed	Horsenettle Cyst from Tobacco	Osborne Cyst from Horsenettle Weed	Osborne Cyst from Tobacco
48.0	48.8	52.0	46.4
54.7	53.6	59.2	48.0
55.4	48.0	51.2	49.9
51.2	48.2	51.5	52.8
52.5	46.4	52.8	50.4
52.0	49.8	51.2	52.0
49.8	48.0	46.6	54.4
52.5	45.6	55.2	49.6
46.7	46.4	48.0	50.9
41.6	51.4	44.8	51.2
46.4	49.6	44.8	44.5
50.9	49.6	51.2	52.8
51.2	49.6	48.0	48.0
41.6	49.6	50.4	54.4
39.2	51.2	53.3	49.6
51.2	54.4	54.1	49.6
48.8	46.4	55.2	44.8
49.6	52.8	49.6	53.6
36.0	54.4	48.3	49.6
54.4	52.0	56.0	46.4
51.2	54.1	53.6	50.4
46.4	60.8	46.9	50.4
33.6	48.0	49.6	46.9
49.6	48.0	48.0	39.2
48.0	50.4	57.6	44.8
51.2	48.3	55.2	57.4
49.6	59.5	48.0	49.6
55.2	48.3	51.2	52.8
48.8	48.8	50.4	49.3
54.4	52.8	53.6	44.8
51.2	49.6	45.6	57.6
56.0	52.0	45.6	41.6
55.2	48.0	51.2	43.2
50.4	48.8	46.4	51.0
52.0	50.4	47.2	57.6
49.6	45.6	48.0	56.0
52.0	49.6	50.4	52.0
50.4	48.0	48.8	55.2
49.6	52.8	32.8	48.0
54.4	51.4	44.8	48.0

TABLE (5 - A) Continued

Horsenettle Cyst from Horsenettle Weed	Horsenettle Cyst from Tobacco	Osborne Cyst from Horsenettle Weed	Osborne Cyst from Tobacco
55.2	52.8	46.9	53.0
53.6	56.0	50.4	44.0
49.6	49.0	50.4	52.8
49.6	52.8	53.6	52.0
48.0	51.2	46.4	53.6
49.6	48.0	49.6	48.0
44.8	51.2	49.6	52.0
49.6	48.0	47.2	58.4
52.8	49.6	49.6	52.8
49.6	49.9	44.8	50.4
49.6	56.8	54.4	47.2
49.6	53.6	53.6	47.2
49.6	48.0	46.4	52.0
51.2	53.6	52.5	43.2
48.0	48.0	52.8	48.0
50.4	52.0	51.2	48.8
52.8	54.4	54.4	52.8
51.2	49.6	53.6	49.6
52.0	54.4	52.0	54.4
52.8	51.2	48.0	48.0
48.0	47.2	48.0	45.6
48.0	55.2	47.2	52.8
49.6	51.2	55.2	52.0
52.8	48.8	46.4	45.6
44.8	51.2	48.0	46.6
48.8	52.8	49.3	56.3
52.0	52.8	52.8	51.2
51.0	54.4	51.2	48.0
56.0	48.0	48.8	47.2
60.8	49.6	49.3	48.8
44.0	52.8	51.2	48.8
52.0	52.0	53.6	53.6
52.8	49.6	43.2	51.2
48.8	52.8	49.6	56.0
48.0	48.8	54.4	52.8

TABLE (6 - A) The observed Values of the Tail Terminal for the Host - Nematode Combinations.

Horsenettle Cyst from Horsenettle Weed	Horsenettle Cyst from Tobacco	Osborne Cyst from Horsenettle Weed	Osborne Cyst from Tobacco
23.2	30.4	27.2	20.8
29.0	32.8	27.2	24.0
29.0	24.8	25.6	25.6
23.8	27.2	27.2	20.8
29.6	25.6	25.6	24.0
24.0	28.8	25.6	22.4
22.4	29.0	24.0	30.4
28.0	25.6	24.0	30.4
31.2	27.2	30.4	30.4
31.8	24.0	25.9	21.6
28.6	27.5	24.0	20.8
28.8	27.2	19.2	20.8
26.1	28.8	25.6	24.0
25.8	28.8	27.2	30.4
27.5	28.0	28.0	27.2
30.6	20.8	20.8	27.2
25.6	30.4	26.4	24.0
33.6	19.2	20.8	24.3
32.0	24.8	26.4	25.6
30.4	28.8	25.6	29.6
22.6	23.2	22.4	25.6
29.0	25.6	27.2	27.2
35.4	24.0	21.6	24.0
30.6	30.4	25.0	27.4
27.2	21.6	24.0	28.0
33.0	24.0	25.6	28.0
32.2	26.4	28.8	24.0
25.8	25.6	24.8	25.6
25.6	24.0	20.8	25.9
31.2	29.3	24.0	25.6
25.6	24.0	28.8	30.4
27.2	26.4	24.4	24.0
30.4	24.8	20.8	22.7
28.8	27.2	22.4	20.8
30.4	25.6	24.0	22.4
32.5	24.0	23.2	32.0
33.6	24.0	21.6	25.3
27.4	26.4	24.8	25.6
28.0	29.6	22.7	27.2
28.8	27.4	25.6	30.4

TABLE (6 - A) Continued

Horsenettle Cyst from Horsenettle Weed	Horsenettle Cyst from Tobacco	Osborne Cyst from Horsenettle Weed	Osborne Cyst from Tobacco
27.2	26.8	23.2	21.6
27.4	28.8	28.8	19.2
30.9	27.2	24.0	21.6
27.7	25.3	22.4	26.9
28.0	24.8	23.2	21.6
24.0	24.0	24.8	30.4
26.9	25.6	22.4	27.2
28.5	23.2	25.6	22.4
19.5	24.0	21.6	19.4
24.2	30.4	19.2	28.0
25.8	29.6	19.2	17.6
25.9	26.9	26.4	24.0
32.0	27.2	21.1	28.0
26.4	27.2	22.4	28.8
28.8	24.0	27.2	21.6
30.4	30.4	24.0	22.4
26.4	20.8	25.9	20.8
27.2	28.8	24.0	27.2
24.0	29.6	24.3	24.0
24.0	24.0	27.2	21.6
24.0	25.8	27.5	24.8
28.8	25.3	22.4	28.0
24.0	22.7	23.2	24.8
30.4	29.6	24.8	17.6
24.0	30.7	28.0	24.0
32.0	27.2	28.8	33.6
25.6	30.4	24.0	33.6
25.1	25.6	19.2	25.6
28.0	24.2	25.6	24.0
33.6	28.8	26.4	20.8
27.2	24.0	25.6	32.0
32.0	24.0	22.4	17.6
32.0	23.2	27.2	19.2
24.0	22.4	22.4	29.6
24.0	30.4	24.0	30.4
25.6	23.2	23.2	25.6
31.2	25.6	25.6	25.6
20.8	24.8	24.0	32.0
27.2	24.8	16.0	28.0
30.4	25.6	17.6	24.2

TABLE (6 - A) Continued

Horsenettle Cyst from Horsenettle Weed	Horsenettle Cyst from Tobacco	Osborne Cyst from Horsenettle Weed	Osborne Cyst from Tobacco
30.4	28.8	20.0	25.6
24.8	27.5	25.6	23.2
20.8	24.0	24.8	25.6
24.0	24.8	26.4	29.6
26.4	24.0	26.4	27.2
22.4	24.2	22.4	26.0
27.2	27.2	24.0	24.8
24.0	24.0	22.1	31.2
33.6	25.6	23.2	36.8
25.6	28.0	24.8	25.6
27.2	26.4	27.2	28.0
24.0	25.6	26.4	22.9
25.6	22.4	22.4	33.6
22.4	29.6	23.2	22.6
25.6	27.2	27.2	28.0
24.0	25.8	27.2	28.0
24.8	31.2	29.6	23.2
27.2	28.0	27.2	22.4
27.2	29.6	22.4	28.8
24.8	24.8	25.6	20.8
21.6	24.0	22.1	26.4
26.4	24.0	20.8	24.0
23.2	28.0	21.3	25.6
28.0	25.6	22.4	22.4
26.4	26.4	20.8	23.2
22.4	31.2	20.8	33.6
23.2	24.0	20.8	24.0
26.4	28.0	21.6	26.4
25.6	22.4	22.4	22.7
28.8	20.8	21.6	24.8
24.0	25.3	24.0	28.0
24.0	23.2	21.6	31.8
24.8	24.8	19.2	25.3
25.6	25.6	20.5	27.4
22.4	29.6	23.5	27.2

ABSTRACT

This thesis is a preliminary statistical study on two nematodes, Horsenettle Cyst and Osborne Cyst. Each of the two nematodes were collected from two hosts, Horsenettle weed and tobacco. For each of the four combinations 115 nemas were selected, and six measurements were taken from each nema.

A test of normality was made to investigate the normality of the distributions of the combinations. Two tests of Homogeneity of Variances were made for combinations which had been considered to be normally distributed. Analyses of Variances were made for the measurement combination which had satisfied the assumptions of normality and homogeneity of variances.

Nonparametric analyses of variance were made for the combinations which had been considered non-normally distributed or had unequal variance.

A discrimination function was estimated to discriminate between any two of the combinations based on the six measurements, and a test of significance for each discrimination function was made. The separation point between each two groups was determined, and the probability of misclassification was computed.