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**SEASONAL APPEARANCE, SAMPLING METHODS, AND ECONOMIC INJURY
LEVELS FOR TARNISHED PLANT BUG IN MICHIGAN DRY BEANS**

By

Anthony William May

THESIS

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ABSTRACT

SEASONAL APPEARANCE, SAMPLING METHODS, AND ECONOMIC INJURY LEVELS FOR THE TARNISHED PLANT BUG IN MICHIGAN DRY BEANS

By

Anthony William May

Information on the population dynamics of the tarnished plant bug; Lygus lineolaris (Palisot de Beauvois), (TPB), can be used in designing effective scouting methods. A two year survey of 12 Michigan dry bean fields in 4 counties was conducted to obtain information on the population changes of TPB in dry beans. Weekly sweep net samples were taken and data was transformed to a logistics curve to analyze population growth through a season. Regression analysis of logistic values on TPB day-degrees was used to calculate when 10%, 50%, and 90% cumulative TPB day-degrees occurred. These results showed 10% occurred at 1178 DD₅₂, 50% at 1495 DD₅₂, and 90% at 1812 DD₅₂ for nymphs, and 10% at 1085 DD₅₂, 50% at 1389 DD₅₂, and 90% at 1693 DD₅₂ for adults. Comparisons between a sweep net method and 2 visual counting methods showed that 80 and 100-sweeps sample and a visual count per 80-feet of row sample, best combined accuracy, precision, and cost efficiency. Economic injury levels were not calculated for TPB in Michigan dry beans because results from damage-yield experiments were in significant.

Results from the study were related to plant phenology. Dry bean plant phenology was recorded each sampling day to determine any effects plant phenology had on population levels of TPB. Weekly sampling showed the greatest number of TPB were collected during the reproductive stages of the plant and peak numbers occurred during pod-fill stage.

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INTRODUCTION

Michigan produces approximately 80% of all navy beans and approximately 30% of all dry edible beans grown in the United States (Michigan Agricultural Statistics 1984). Each year dry bean growers spend large amounts of money controlling plant-damaging insects. For one pest, the tarnished plant bug; Lygus lineolaris (Palisot de Beauvois) (TPB), insecticides are the only control measure available (R. F. Ruppel, Michigan State University, personal communication). Knowledge of economic injury levels is essential to the establishment of an efficient chemical spray program, according to Pedigo (1972). However, no information on economic injury levels for TPB in dry beans is available to growers. Armed with a definitive economic injury level for TPB, dry bean growers can achieve better control by applying more timely chemical treatments.

The efficiency of a chemical spray program is likewise increased when applications are based on accurate estimates of pest density in the field. In Michigan, IPM scouts and growers use several different methods to estimate TPB density in dry beans. However, none of these methods have been compared to an absolute density count to determine their accuracy.

The objectives of this study were to determine the economic injury levels of TPB on dry beans and to find an accurate and precise method to estimate TPB density in the field. Included in the study were phenologic models of the insect and plant, and a report on population changes of TPB in dry beans.

LITERATURE REVIEW

Taxonomy

Beginning with Linnaeus (1746), the nomenclature of TPB has undergone numerous changes. Khattat (1978) and Zia-ud-Din (1950), reviewed in detail the chronology of these changes. The following outline lists all names given to the TPB.

<u>Cimex griseus</u>	Linnaeus 1764
<u>Coreus lineolaris</u>	Palisot de Beauvois 1818
<u>Capsus oblineatus</u>	Say 1831 (Hughes 1943)
<u>Phytocoris lineolaris</u>	Harris 1841 (Crosby and Leonard 1914)
<u>Lygus pratensis</u>	Feiber 1861
<u>Tarnished plant bug</u>	Riley 1870 (Crosby and Leonard 1914)
<u>Lygus pratensis</u> L.	Uhler 1886 (Slater and Davis 1952)
<u>Lygus pratensis</u> var. oblineatus	Knight 1917
<u>Lygus oblineatus</u>	Knight 1941
<u>Lygus lineolaris</u> (P. de B.)	Slater and Davis 1952
<u>Liocoris lineolaris</u>	Kelton 1955
<u>Lygus lineolaris</u>	Carvalho 1959
<u>Lygus lineolaris</u>	Kelton 1975

BIOLOGY

According to Taksdal (1961), the TPB has an extensive host range including 120 plant species representing 30 families. Many economic crops throughout the world are damaged by this insect. Extensive lists of cultivated plant and weed hosts are available (Frye 1980, Malcolm 1953, Romero 1972, Taksdal 1963, Tingey and Pillemer 1974). Numerous types of cultivated beans are affected each year by TPB feeding, including dry edible beans, Phaseolus vulgaris L.

The TPB has 2 to 4 generations per year depending on geographical location. Ridgway and Gyrisco (1974), and Wheeler (1974) report that 2 generations have been determined and a third is likely in New York. He observed all stages of development in the field from mid-May until frost. At least 2 generations of TPB were recorded in Vermont by Hauschild and Parker (1974). Khattat (1978), reports 3 overlapping generations in Canada.

This insect overwinters as an adult in weedy areas, heavy duff and other sheltered areas (Prokopy et al. 1979, Pruess 1974, Ridgway and Gyrisco 1960, Wheeler 1974). Studies in Washington state indicate survival of overwintering adults is affected by the moisture level in the hibernaculum (Frye 1981). Frye also indicated that TPB are well adapted to the extreme temperatures in Central Washington state and that emergence is influenced mainly by temperature with moisture level having a minimal influence.

Lygus species become more active during winter months whenever temperatures are sufficiently warm. Lygus hesperus (Knight) and Lygus elisus (Van Duzee) were collected in yellow colored traps during 3 winters, on days

when temperatures exceeded 9.4°C (Landis and Fox 1972). Also, considerable activity was observed during February and March in some years. In California, *Lygus* species enter a facultative non-reproductive diapause during winter months, but remain active (Beards and Strong 1966).

Spring emergence of overwintering adult TPB occurs in April or May. Ridgway and Gyrisco (1960) state that females begin laying eggs in early May. Also, they report significantly more females than males were caught in tanglefoot traps after spring emergence began. These results are not conclusive because the number caught was quite low. In Michigan, overwintering adult TPB were observed feeding in alfalfa during the first week in May (Romero 1972).

Overwintering females appear to be selective when choosing oviposition sites in the spring. Alfalfa, clover, and certain early season weed species are suitable hosts, while apple, pear, quince and plum are not (Crosby and Leonard 1914).

First generation nymphs appear sometime in May depending on geographical location. The nymphs molt 5 times before reaching the adult stage (Ridgway and Gyrisco 1960). Taxonomic descriptions of TPB nymphs are given by Painter (1929) and of adults by Knight (1941). Survival of nymphs is greatest when eggs are deposited on suitable hosts (Stevenson and Roberts 1973, Strong and Kruitwasen 1969, Wanderzant 1967). In their host plant preference studies, Curtis and McCoy (1964) found that the stimuli which mediate selection of an oviposition substrate are not based on nutritional quality, however the mechanism responsible for host preference is obscure. TPB females are nevertheless capable of discriminating oviposition hosts from feeding hosts.

Development from egg to adult in the lab under controlled conditions takes 46 days at 0°C, 28 days at 25°C, 22 days at 30°C and first instars perished at

35°C. Additional information on rates of development for each stage, incubation periods, and preoviposition periods are given by Ridgway and Gyrisco (1960). In experiments done with L. hesperus, population increase was greatest at a constant temperature of 90°F or alternating temperatures of 80-90°F (Strong and Sheldahl 1970). Field reports on TPB indicate that populations gradually increase in early summer and peak in late summer when temperatures are consistently high. Sweep net collections from alfalfa fields and weedy areas in Michigan indicate August is when TPB populations reach their peak (Ruppel and Tesar 1982).

A different situation occurs in bean fields because TPB populations are primarily migratory adults. During flower bud formation, blossoming and small pod stage, TPB migrate into bean fields (Broesma 1968, Carlson 1959, Khattat and Stewart 1975, Scales and Hackaylo 1974, Shorey et al. 1965). Migration of TPB into bean fields can occur at any time, but the onset of floration attracts the greatest number. Removing sources of food and shelter can also stimulate lygus species to migrate into more favorable surroundings. Poston and Pedigo (1975) found that TPB moved into soybean plots from cut alfalfa.

TARNISHED PLANT BUG DAMAGE

Much has been written on the nature of lygus bug damage to economic crops. Tingey and Pillemer (1977) reviewed many of these reports and concluded that lygus bugs (TPB included) cause characteristic types of plant damage. They arranged these types of damage according to symptomatology: 1) tissue malformation, 2) abscission of fruiting forms, 3) localized wilting and tissue necrosis, 4) morphological deformation of fruit and seed, 5) altered vegetative growth. Lygus damage results from feeding of the insect on the plant. Symptoms of plant damage can be directly related to different feeding sites, plant response to insect feeding, and to the mechanical feeding process itself. There are several different symptoms of TPB damage in dry beans depending on which of these factors is involved. Common symptoms of TPB damage of dry bean plants are given in Table 1.

In most reports of TPB damage to dry beans, reference is made to a "toxic salival" substance injected into the plant through the insect's stylets. Work done with several species of lygus prove that these insects do emit a toxic substance during feeding. The earliest report, (Smith 1920), showed that tissue macerates of salivary glands from Lygus (= Lygocoris) pabulinus, caused tissue necrosis when applied to potato slices. Experiments conducted to identify this toxic substance indicate lygus bugs emit an auxin inhibitor into the plants. Tingey and Pillemer (1974) developed a theory on auxin inhibition. Their theory is based on the work done by Fisher et al. (1946) in which foliar applications of naphthaleneacetic (NAA) reduced flower abscission in beans fed on by TPB. Scott (1970)

Table 1. Tarnished plant bug damage reported in dry beans.

Types of damage	Symptom	References
Stunting and deformation of growth	Altered vegetative growth	Taksdal 1963
Blasting of buds, blossoms, flowers and small pods	Localized wilting and tissue necrosis, abscission of fruit	Taksdal 1963
Stings and discoloration of seeds	Morphological deformation of fruit and seed	Shull and Wakeland 1931

hypothesized that L hesperus and L elisus inject a plant auxin (possibly beta-indoyl acetic acid) into developing seeds of carrots and beans. Numerous biologically-active substances have been found in the saliva and salivary glands of lygus bugs, including: enzymes, amino acids, plant growth promoters and inhibitors (Tingey and Pillemer 1977). It appears from the findings of these many investigations, that a wide variety of toxic substances are involved in lygus damage to plants.

In addition to the injection of toxic substances, TPB withdraw plant juices, causing injury to the plant. Mechanical damage caused by probing and the injection of toxic substances rupture plant cells which release their juices. Strong (1970) reports that it takes only 23 seconds for one L hesperus adult to empty the liquid contents of an alfalfa flower bud. Lygus bugs probe repeatedly until a suitable feeding site is located. The repeated probes of its barbed stylet causes extensive damage to plant tissues. According to Strong (1970), much of the plant damage caused by L hesperus is attributable to the destruction of the meristematic tissues. Damage to the meristematic tissues of a plant are extremely harmful because auxins produced in these tissues are needed for numerous plant processes such as regulation of abscission in vegetative and fruiting structures (Thimann 1972). The TPB induces abscission of flower buds and blossoms in bean plants by feeding on the ovules located in these structures. It punctures the ovules with its stylet, causing enzymatic and mechanical damage which disrupts normal production of auxins. Abscission results from an increased production of abscission(s) and a decreased production of auxin(s) (Khattat and Stewart 1975). A common term used to describe this kind of damage is "blasting". Flowers can be blasted also. Similar damage is caused in bean pods.

Tarnished plant bugs puncture the developing seeds and disrupt normal growth processes necessary for pod maturity. Pod development is controlled by plant hormones (i.e. auxins) produced by the developing seeds (Street and Opick 1970). Abscission of the pods results from an increased production of abscission(s) by damaged seed. Damage to developing seeds can also result in small, shriveled seeds. In addition to the blasting of pods, TPB cause "stings" and discoloration of bean seeds. The term "sting" refers to a puncture or dimple left on the seed coat after the TPB inserts its stylet. Shull and Wakeland (1931) studied this type of seed damage and observed large, loose starch granules beneath the punctured seed coat as well as discoloration of the surrounding area. Their attempts to simulate this type of damage using artificial means resulted in discoloration of the seed coat but no "stinging". No reports are available on the exact cause of this type of damage.

SAMPLING METHODS

A diversity of methods are used to sample plants for TPB. Two methods which are used quite extensively, are the visual count and sweep net methods. Characteristics that make these methods popular to use are: minimal equipment is needed, ease in execution, accurate estimates are obtained, and most economic crops can be sampled with one or the other. In some situations the visual count and sweep net methods are used together such as in an apple orchard (Prokopy et al. 1982). Various other methods have been used experimentally to sample for TPB such as: a boom supported D-Vac vacuum (birdsfoot treefoil), a tractor-mounted "Nisbet Bug Catcher" (cotton), a drop cloth technique (fruit orchards and cotton), and several types of sticky traps (Beal 1935, Gray and Treboar 1933, Mueller and Stern 1973, Mukerji 1973, Prokopy et al. 1982, Race 1980). All of these methods, with the exception of the drop cloth method, are not used in commercial fields.

With the increasing popularity of university-based crop monitoring programs, more attention is being given to sampling than ever before. Five university crop monitoring programs employ variations of the visual and sweep net methods to sample bean fields for TPB (Georgia 1981, Michigan State 1981, Minnesota 1981, Purdue 1981, and Wisconsin 1981). The number of sweeps/sample and the number of samples taken per field vary with each university. For instance, Michigan State University instructs its scouts to take 5 samples (100 sweeps/sample) per field, as opposed to the University of Wisconsin which instructs its scouts to take 10 samples (25 sweeps/sample) per 100 acres. Each university employs its own variation of the visual method in terms of the

number of plants examined per sample, the length of row examined per sample, and number of samples taken per field. Michigan State University's scouts use the following variations: examine 10 plants in 5 locations per field, or 15 ft of row in 5 locations per field, or 4 leaves on each of 10 plants in 5 locations per field.

ABSTRACT

POPULATION DYNAMICS OF THE TARNISHED PLANT BUG IN MICHIGAN DRY BEAN FIELDS IN RELATION TO PLANT PHENOLOGY

By

Anthony William May

Population dynamics of the tarnished plant bug were estimated from sweep net collections taken during 1981 and 1982. The sweep net collections were transformed to their logistic equivalents and then incorporated into a TPB day-degree model with a base temperature of 52°C. Regression analysis of the logistic values on insect day-degrees was used to estimate when 10%, 50% and 90% of the TPB cumulative day-degrees occurred. Peak numbers of adults and nymphs were collected while plants were in the R3-R7 stages. Regression analysis showed 10% cumulative day-degrees occurred at 1178 DD₅₂, 50% at 1495 DD₅₂, and 90% at 1812 DD₅₂ for nymphs, and 10% at 1085 DD₅₂, 50% at 1389 DD₅₂, and 90% at 1693 DD₅₂ for adults. Plants were in the R2 stage at 10%, R7 stage at 50%, and R9 stage at 90% TPB cumulative day-degrees.

INTRODUCTION

An asset to any pest management program is understanding the dynamics of the pest. Questions commonly asked by growers and entomologists alike are: "when should scouting begin?"; and "when will the pest population reach its peak?". Studies on the population dynamics of the TPB have been done for various crops (Butler and Wardecker 1970, Frye 1980, Ridgway and Gyrisco 1960, Stitt 1940). In their studies with soybeans, Broersma and Luckman (1970) found TPB populations begin increasing during flowering and peak during small pod stage. They believe TPB were attracted to the lush, succulent foliage, flowers and fruit. In dry bean fields, migration and subsequent population increase of TPB in dry bean fields are believed to occur when flowers and pods are present. Although seasonal appearance and relative abundance of the TPB in Michigan dry beans have been studied (Ruppel and Jennings 1979), population dynamics have not been studied in relation to plant phenology.

The objective of this study was to investigate the dynamics of the TPB in Michigan dry bean fields and relate them to dry bean plant phenology.

MATERIALS AND METHODS

Twelve dry bean fields representing the major dry bean growing counties in Michigan, were sampled during 1981 and 1982 for TPB (Table 2). Population changes were estimated using the sweep net method. Although this method does not give an absolute count of insects in a region, it can estimate population changes (Butler and Wardecker 1970, Fye 1980, Johnson et al. 1957, Ridgway and Gyrisco 1960). In 1981, 40-sweeps were taken from a single row and replicated 8 times per field. The sampling regime used in 1982 was based on 1981 research (May 1984). Four subsamples (20-sweeps ea.) taken in succession and from the same row, comprised a single sample. The number of samples taken per field ranged from 1-4, averaging 2 per field. The reason for using 20-sweep subsamples was that less foliage was collected in 20-sweeps as compared to 80 continuous sweeps. In the 1981 research results, 80-sweeps was a more precise sample size than 20-sweeps. Both techniques were combined and used in the 1982 survey.

Dry bean plant development was estimated in each field on each sampling day. Estimates made in 1981 were based on a survey of 20 representative plants which were removed from the field and examined. The 1982 estimates were based on 50 representative plants examined in the field. The system devised by Fehr et al. (1974) for soybean phenology and later adapted to bush and vine type common bean varieties by Lebaron (1974), was used to determine dry bean plant development stages. This system was used because the common bean and dry bean plants have similar development stages. Bean development according to Fehr's system involves a series of vegetative stages followed by a series of

Table 2. Dry bean fields sampled during 1981 and 1982 surveys.

1981 Fields

1.	Crapo Road Field, Gratiot Co.,	T10N	R2W	Sec 22
2.	Tyler Road Field, Gratiot Co.,	T10N	R3W	Sec 21

1982 Fields

3.	Centerline Road Field, Clinton Co.,	T6N	R1W	Sec 31
4.	Chandler Road Field, Clinton Co.,	T6N	R1W	Sec 30
5.	W. French Road Field, Clinton Co.,	T7N	R2W	Sec 20
6.	English Road Field, Tuscola Co.,	T11N	R10E	Sec 36
7.	English Road Field, Tuscola Co.,	T11N	R10E	Sec 36
8.	Hensey Road Field, Lapeer Co.,	T7N	R11E	Sec 32
9.	Prtow Road Field, Lapeer Co.,	T7N	R11E	Sec 23
10.	Newark Road Field, Lapeer Co.,	T7N	R11E	Sec 28
11.	Lake Pleasant Road Field, Lapeer Co.,	T7N	R11E	Sec 27
12.	Collins Road Field, Ingham Co.,	T4N	R2W	Sec 36

reproductive stages. Vegetative stages encompass the period of plant growth from seedling to blossom. Each vegetative stage is determined by counting the number of nodes on the main stem and by checking leaf development. Vegetative stages are denoted by a number which coincides with the number of nodes present (i.e. V1=first vegetative stage).

Reproductive stages encompass the period of plant development from blossom to senescence. These stages are also denoted by a number coinciding with the nodal count and includes: pod development, % of plant population showing bloom, and color of leaves in their descriptions (i.e. R4=fourth reproductive stage). The individual vegetative stages for the common bean plant are outlined in Table 3. These stages are the same for bush and vine varieties. Reproductive stages on the other hand differ according to plant variety. Individual reproductive stages for the bush and vine varieties are outlined in Table 4 and 5 respectively. By relating population changes to plant development, growers, scouts, and crop consultants will have a more definite idea of when to expect TPB in the field.

The phenology of the TPB in Michigan dry bean fields was calculated using the method explained by Ruppel (1982). In this method each individual sweep sample of TPB were accumulated per field and then fit to sigmoid curves. Transformations of sample dates to day-degrees (base 52°F) and percent accumulated TPB numbers to logistic values were used to construct growth curves. The logistic values for all TPB samples were pooled and a regression analysis of these values on accumulated day-degrees was used to estimate when 10%, 50%, and 90% cumulative TPB day-degrees (base 52°F) occurred. The base temperature of 52°F used for the insect day-degree model was calculated from a regression analysis of TPB development rates on temperature. Ridgway and Gyrisco (1960) recorded TPB development rates at various temperatures and the

Table 3. Vegetative stages in the development of the common bean plant (Phaseolus Vulgaris L.).

Stage No.	General Description (vegetative stages)	Nodal Count
VI	Completely unfolded leaves at the primary (unifoliate) leaf node.	1
V2	First node above primary leaf node. Count when leaf edges no longer touch.	2
V3	Three nodes on the main stem including the primary leaf node. Secondary branching begins to show from branch of V1.	3
V(n)	n nodes on the main stem, but with blossom cluster still not visibly opened.	A new node/ 3 days
V5	Bush (determinate) plants may begin to exhibit blossom and become stage R1.	5
V8	Vine (indeterminate) plants may begin to exhibit blossom and become stage R1	8

Table 4. Reproductive stages in the development of bush varieties of the common bean plant (Phaseolus vulgaris L.).

Stage No.	General Description (reproductive stages)
R1	One blossom at any node.
R2	Pods one half inch long at first blossom position, usually nodes 2 to 3.
R3	Pods one inch long at first blossom position. Secondary branching at all nodes, so plant is becoming denser, but not taller. 50% bloom.
R4	Pods three inches long—seeds not discernible. Bush varieties may be shorter.
R5	Pods 5-6 inches long, maximum length. Seeds discernible to feel in garden varieties. Bush variety pods 3-4 inches. Seeds discernible.
R6	Seeds at least one fourth inch over long axis.
R7	Oldest pods have developed seeds. Other parts of plants will have full length pods with seeds almost as large as first pods. Pods will be developing over the entire plant.
R8	Leaves yellowing over half of plant, very few small pods and these in axils of secondary branches, small pods may be drying. Point of maxium production has been reached.
R9	Mature, at least 80% of the pods showing yellow and mostly ripe. Only 40% of leaves still green color.

Table 5. Reproductive stages in the development of the vine varieties of the common bean plant (Phaseolus vulgaris L.).

Stage No.	General Description (reproductive stages)	Nodal Count
R1	One blossom at any node. Tendril will begin to show.	8
R2	Pods one half inch long at first blossom position. Node 2 to 5 in most plants. Blossom would have just sluffed.	9
R3	Pods one inch long at first blossom position. Pods are showing at higher nodes when blossom sluffs. 50% bloom.	10
R4	Pods two inches long at first blossom position.	11
R5	Pods three plus inches long, seeds discernible by feel.	12
R6	Pods 4-5 inches long with spirs (maxium length). Seeds at least one fourth inch in long axis.	
R7	Oldest pods have fully developed green seeds. Other parts of plant will have full length pods with seeds near same size. Pods to the top and blossom on tendril, nodes 10-13.	
R8	Leaves yellowing over half of plant, very small new pods and blossoms developing. Small pods may be drying. Point of maxium production has been reached.	
R9	Mature, at least 80% of pods showing yellow and mostly ripe. Only 30% of leaves are still green.	

smallest coefficient of variation occurred at 52°F. This method used for plotting TPB phenology has been used to describe the phenology of other insects in Michigan dry beans (Ruppel and Jennings 1979).

RESULTS

Regression analysis show 10% seasonal abundance of TPB nymphs occurred at 1178 DD₅₂, 50% at 1495 DD₅₂, and 90% at 1812 DD₅₂ (Figure 1). Seasonal abundance results for TPB adults were as follows: 10% at 1085 DD₅₂, 50% at 1389 DD₅₂, and 90% at 1693 DD₅₂ (Figure 2). Plant development stages at these accumulated TPB day-degrees were averaged from all the fields. Plants were in the R2 stage at 10%, R7 stage at 50% and R9 stage at 90% abundance of TPB nymphs (Figure 1). Plants were in the R2 stage at 10%, R7 stage at 50% and R9 stage at 90% abundance of TPB adults (Figure 2). Peak numbers of adults and nymphs were collected from 1300 to 1500 DD₅₂ with plant development estimated at R3-R7 during this period.

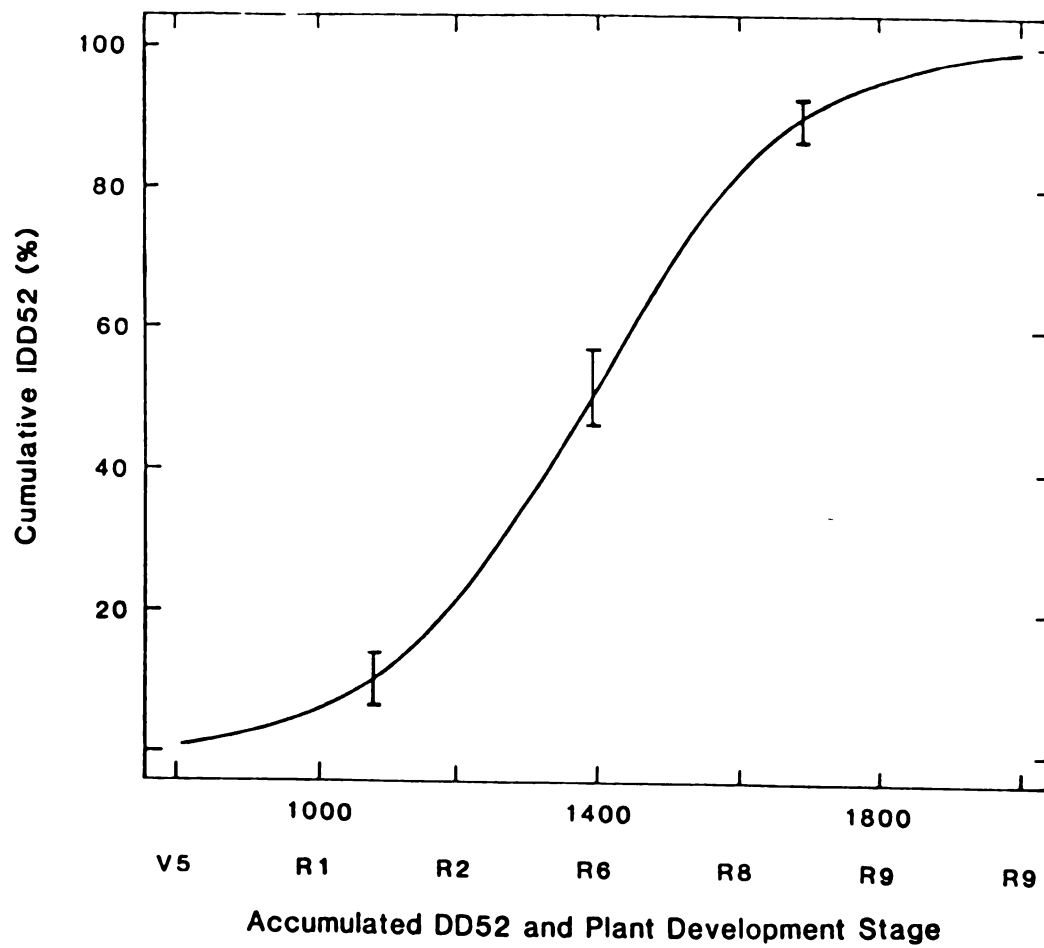


Figure 1. Cumulative percent of adult TPB day-degrees (DD) on accumulated day-degrees (base 52°F) for 1981 and 1982.

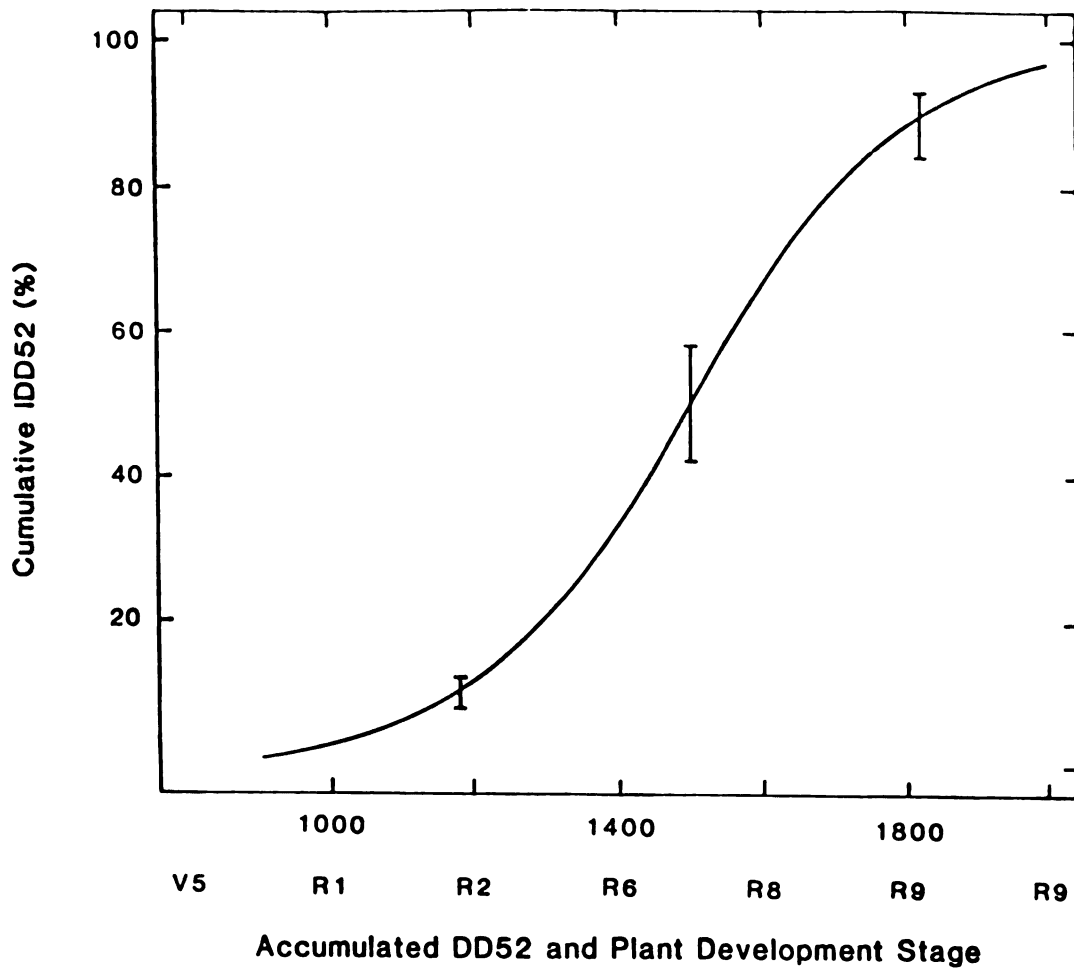


Figure 2. Cumulative percent of TPB nymph day-degrees (DD) on accumulated day-degrees (base 52°F) for 1981 and 1982.

DISCUSSION

Results from the plant phenology and seasonal appearance surveys agree with earlier reports that TPB increase in number beginning at small pod stage. The fact that peak numbers of TPB were collected during podding implies conditions were optimum for the growth of nymphal and adult populations. Factors contributing to this increase in numbers of TPB were the availability of suitable food sources and oviposition sites. Bean pods serve as both a food source and oviposition site for TPB. Data collected in this study indicates the need to begin sampling dry bean fields before pod stage so that appropriate control measures can be implemented if needed. A suitable starting point for sampling would be the first week of flowering, to detect any buildup of TPB populations. Scouting before flower stage is not necessary.

ABSTRACT

COMPARISONS OF THREE SAMPLING METHODS FOR ACCURACY AND PRECISION AND COST IN ESTIMATING TARNISHED PLANT BUG DENSITY IN DRY BEAN FIELDS

By

Anthony William May

Three methods, a sweep net and two visual methods, were compared to an absolute method to determine their accuracy. Accuracy of the sampling methods was determined by comparing their mean square errors (MSE) to the MSE of the absolute method. Sample standard deviation to sample mean ($s/\bar{x}$) ratios were used as a criterion for precision tests. Six precision tests were conducted in which various sample sizes were compared to determine which was most precise. The cost of each sample size was calculated by recording the time required to complete the sample multiplied by a fixed cost/unit of time. Best methods were 100 and 80 sweeps/sample and a visual count per 80 feet of row.

INTRODUCTION

An important component of any insect control program is sampling. Reliable and accurate sampling data used in making treatment decisions, can increase the program's effectiveness and efficiency. Reliable estimates of TPB density in dry bean fields are useful in deciding when insecticides would be applied. Current methods being used to estimate TPB density in Michigan dry beans are visual counts and sweeping with an insect net.

These methods have not been scientifically tested to determine their accuracy and precision in dry bean fields. The present study was undertaken to determine an accurate, reliable and efficient method for sampling Michigan dry bean fields for the TPB.

The sweep net method is extremely popular for sampling in field and forage crops for the TPB and many other species. Some crops sampled with the sweep net are: cotton (Sevacherian and Stern 1972), beans (Stewart and Khattat 1980), alfalfa (Mukerji 1973), birdsfoot trefoil (Ridgeway and Gyrisco 1960) and safflower (Muller and Stern 1973). The visual counting method is commonly used in sampling orchards and small fruit for the TPB (Prokopy et al. 1982, Schaeffers 1972). Both of these methods collect or count a portion of the population in a field and their results are used to estimate the population throughout the field. Morris (1960) and Southwood (1978) refer to these methods as population indices. Population estimates based on indices are less accurate than estimates based on direct counts of individuals in a specified area (i.e. no. of insects /m²). However, it is too time consuming to directly count all TPB in a specified area, particularly in a large field where several repetitions are necessary. A common

practice used to increase the accuracy of population indices is to correct the data by comparing and/or calibrating it with an absolute estimate. Counting all the TPB in a specified area is the way to obtain an absolute count. Stewart and Khattat (1980) calibrated sweep samples (50 sweeps/sample) to absolute counts using regression analysis. A D-Vac suction apparatus was used to obtain an absolute count of TPB density per 10 bean plants. The value of calibration is that an absolute population count can be estimated from a population index (Southwood 1978).

Another important characteristic of a sampling method is its precision. The precision of a sampling method is a measure of dispersion around the sample mean or expected mean (Fowler and Witter 1982).

The final criterion used in comparing the 3 sampling methods is cost. Growers consider the cost of a sampling method as important as precision and accuracy. Cost was calculated on a dollar/sample basis. The time required to complete a sample was multiplied by a fixed rate of \$5.00/hr and the result was the cost.

The objectives of this study were to (1) compare the accuracy of 3 sampling methods, (2) to test several variations of each method to determine which exhibited the least variation, and (3) to evaluate the methods based on precision, accuracy and cost.

MATERIALS AND METHODS

Accuracy and precision tests were conducted in 2 dry bean fields in Gratiot County in 1981, and in a dry bean field on the Michigan State University campus in 1982.

Sampling Methods

The sampling methods included in these comparative studies were: sweep net, visual count per distance of row, and visual count per time.

Sweep net - Sweeping was done with a standard 38 cm diameter insect net, down the row and with a pendulum motion. One sweep was taken approximately every 3 ft. The nets used in this experiment were made of cloth and retained all adult and nymphal TPB caught. Sweeping was done down the row primarily because the author felt each plant was being sampled with this technique, as opposed to sweeping perpendicular to the row which does not sample each plant. Ruesink and Haynes (1973) showed there was no significant difference in the numbers of cereal leaf beetles caught with sweeps taken across the row or down the row. A pendulum motion was used because it was easier to execute and in the author's opinion, less variable than the 180° motion. The speed of the sweeps was kept as consistent as was humanly possible.

Visual count per distance of row - A count was made of all TPB observed while walking a specified distance. The immediate 3 rows on the right and left were visually searched while walking at a constant speed. This method resembled the line transect method of Southwood (1978) in which the number of insects seen will be a reflection of their density. Each TPB was positively

identified before it was counted and care was taken not to count the same insect twice. Plants were not disturbed intentionally while walking.

Visual count per time -The observer remained in a stationary position in the field, and counted the number of TPB observed during a specified amount of time. Only the immediate 3 rows on both sides and approximately 8 ft in front and behind the observer was checked.

Cage-Absolute population counts can be obtained with cage techniques, as described by Kretzschmar (1948) and Pedigo et al. (1972). Cages were used in this study to obtain absolute counts of TPB populations in the field. Each cage consisted of a wood frame, covered with Saran mesh (52 x 52 per inch), and were 54 in X 54 in at the base (Figure 3). A cage sample consisted of placing the cage over 2 rows of beans (ca. 99 plants in the fields tested during 1981, and 128 plants in the field tested in 1982). In each sample, all plants were thoroughly examined twice before moving the cage to a new site. All TPB found in the cages were collected with an aspirator and then released.

1981 Accuracy Tests

Both fields were sampled at approximately 3 day intervals (July 15 - September 2) depending on weather and field conditions. A randomized block design was used in which the testing areas were divided into 8 equal sized plots (18.66 ft X 125 ft). Topography and plant stand were uniform throughout the blocks. Black turtle beans were grown in one field and Sanilac beans in the other. Each sampling method was executed 1/block, 8/field/day. This number of cages was used because the vehicle used to transport them could not accommodate more than 5 cages and because the sampling was more time consuming when fewer cages were used. A general scheme was used in choosing sites for the cages: the testing area was divided into 4 equal sized portions with

4 samples taken from the center of each portion. Four samples were also taken from the approximate center of the testing area (Figure 4).

The sample sizes used in these tests were: (1) 20 sweeps taken in succession and from the same row (8 reps = 160 sweeps/field/day), (2) count the number of TPB observed while walking 40 ft of row at approximately 10 ft per 3 min (8 reps = 320 ft/field/day), (3) count the number of tarnished plant bugs observed in 4 min while standing in a stationary position (8 reps = 32 min/field/day). These sample sizes were chosen arbitrarily and were not previously tested by the author.

This sampling regime required approximately 4-5 hours to complete per field. Starting times for the tests varied throughout the season with the majority of the morning sampling being done in the Sanilac bean field while the afternoon sampling was done in the Black Turtle bean field. On the occasion when only 1 field was done per day, starting time was approximately 9:00 to 10:00 AM. The sequence in which the methods were tested was: first the visual per time method, followed by the visual per distance of row and then the sweep net methods.

1981 Precision Tests

Precision tests were conducted during 3 different development stages of the dry bean plant. These stages were: vegetative, reproductive and post reproductive. These 3 periods in the development of the dry bean plant were chosen because TPB densities in bean fields (soybean and dry bean) are generally low during the vegetative period, high during the reproductive period, and somewhere between high and low during the post reproductive period, with the density decreasing during plant senescence (Broersma and Luckman 1970, Hagel 1978, Khattat and Stewart 1975, Ruppel and Jennings 1979). The purpose for



Figure 3. Cages used to obtain absolute population level estimates.

conducting the experiments during these development stages was to evaluate the performance of each method at these densities. Various sample sizes were used to determine the most precise sample size for each method (Table 6). The purpose for testing various sample sizes at these densities was to determine if their precision varied with each density level. A range of sample sizes was chosen so compatible studies could be done on small and large sample sizes.

The sampling regime used in these experiments required approximately 8 hours to complete. On each sampling day, testing began at approximately 8:30 - 9:00 AM, with the visual per time method first, followed by the visual per distance of row and the sweep net methods. This sequence was chosen because early in the morning visual sampling is most appropriate due to plant wetness. The author chose to begin sampling in the morning with the visual per time method because it involved less movement among the plants and the sampler remains drier. Sampling at mid-day was done with the visual per distance of row method because TPB are active during this part of the day and the visual method is more appropriate than the sweep net.

In determining the most efficient sample size for each method a cost factor must be included because time and money are major constraints in all sampling procedure. Cost is measured in minutes required to complete a particular method. Each sample is timed from its start to its finish. Sweep net samples are timed from the start of sweeping to the finish of bagging the sample. Visual methods are timed from the start of counting to the completion of either the time period or the distance of row.

1982 Accuracy Tests

Sampling was done on a regular basis but did not begin until TPB were seen in the field (July 21 - August 27). This measure improved the chances of positive

Table 6. Sample sizes used in 1981 precision tests.

reps ^a	Sweep net	Visual/time		Visual/distance	
	sample size (sweeps)	reps	sample size (minutes)	reps	sample size (feet)
8	10	8	1	8	10
7	20	7	2	7	20
6	30	6	3	6	30
5	40	5	4	5	40
4	50	4	5	4	50
3	60	3	6	3	60
2	70	2	7	2	70
1	80	1	8	1	80

^a Replications

results unlike the early sampling days of 1981. Several other changes were made in the accuracy tests and they were: 80-sweep samples rather than 20-sweep samples, 80-ft of row rather than 40-ft of row, and 8-min samples rather than 4-min samples. Changes in sample sizes were based on the results from the 1981 accuracy tests. Sampling was started each day in late morning (i.e. 10:00 - 11:00 AM) to allow the bean plants to dry off. A completely randomized design was used in the 1982 tests because the author thought the randomized block design (1981) involved too much traffic in the plots and caused excessive "flushing" of the TPB. Sampling methods were assigned to plots by randomly selecting numbered pieces of paper from a jar. The numbers on the pieces of paper coincided with the number of plots in the field so that the jar contained 20 pieces of paper numbered 1 through 20. In this technique randomization was done without replacement. The randomization ritual was repeated on each sampling day.

Cultural Practice - The experimental plots were located on a 3 acre field at the Collins Road research facility. The field was unused in years past and had to be plowed and fitted for planting. Several soil probes were taken from the field and a composite sample was sent to the MSU soil diagnostic lab. In accordance with the recommendation from the diagnostic lab, 1 ton of 6-24-24 fertilizer was applied on June 2, 1982. Certified Sanilac variety seed was planted on June 8, 1982 in 28 in rows and at a density of 14.2 seeds per ft. A pre-plant application of Eptam and Treflan (1 1/4 qt/A and 1 pt/A), and a post emergence application of Amiben (1 qt/A) served as weed control for the season. The actual testing area contained 60 rows with plots consisting of 6 rows. As a result of the change in experimental design, more plots were needed for the 1982 tests. In addition, at least 250 ft was needed in each plot to execute 80 sweeps. The maximum number of plots that satisfied all conditions was 20, which

resulted in a change in the number of replications from 1981. Five replications of all methods including the absolute counts, insured that all the plots were used on each sampling day.

Twenty absolute counts were taken per sampling day as described in the 1981 tests. Sweep net samples were not bagged as was done in 1981 rather they were counted in the field and the insects were released.

1982 Precision Tests

Three precision tests were conducted in 1982 but not at the 3 development stages of the plant as in 1981 (July 26-August 22). The precision tests were conducted when results from the accuracy tests indicated low, medium and high population levels of TPB were present. Standards for these levels were arbitrarily chosen: low=1 TPB/20 or more plants, medium=1 or more TPB/5 plants, high=1 or more TPB/ 1 plant. Larger sample sizes were used in the 1982 tests to determine if precision was significantly increased with a larger sample size (Table 7). Samples were not consolidated as in 1981 because methods used in both precision and accuracy tests should be executed in the same manner. For instance, a 4-minute visual count used in the accuracy tests is not the same method as the sum of 4(1 min) visual counts used in the precision test. Variations of each method were assigned a specific starting order while the methods themselves did not follow a prescribed sequence. All samples were counted in the field and all TPB collected with the sweep net were released.

Analysis

Accuracy of each sampling method was determined by comparing their mean square error (MSE) to the MSE of the absolute counts. The method whose MSE varied least from the MSE of the absolute count was most accurate. A second method used to compare the accuracy of sampling methods is calibration.

Table 7. Sample sizes used in the 1982 precision tests.

Sweep net			Visual/time		Visual/distance	
reps	sample size	starting order	sample size	starting order	sample size	starting order
5	10	2	1	2	10	2
5	20	3	8	3	20	4
5	80	4	16	1	80	3
5	100	1			249	1

According to Southwood (1978), calibration can be used to improve the accuracy of population indices (i.e. sweep net samples, visual counts) by regression analysis of each index on an absolute count (i.e. cage sample). Comparisons of the improved accuracy (i.e. slope of the regression line) of each index can be made and the most accurate index can be determined. The formula used in the calibration process is the regression equation:

$$Y = a + bx$$

where:

Y = estimate of the field mean of TPB collected with the sweep net or one of the visual methods

a = regression coefficient (intercept)

b = slope of the regression line

x = estimate of the field mean of TPB collected with the cages

Daily field means of the number of TPB collected were calculated for each sampling method. The purpose for calculating field means was to equalize the number of samples for all sampling methods and thus enable a regression analysis to be conducted. The slope (b) of each method's regression line represents their respective calibration factors. Comparisons of the calibration factors of each method were done using this formula:

$$\frac{\bar{bx}_1}{\bar{bx}_2}$$

The method which had the largest positive slope was most accurate. Calibration is often used to increase the accuracy of sample estimates such as sweep net catches of lygus bugs in cotton (Falcon et al. 1971).

Precision of sample estimates is often measured by using the ratio (s/x) of the sample standard deviation to the sample mean (Fowler and Witter 1982, Rudd

and Jensen 1977). This ratio serves as an indicator of the variability among estimates. The sample size with the lowest ratio (s/x) was considered the most precise for that particular sampling method. A coefficient of variation was calculated for each sample size tested. The coefficient of variation is a measure of variation and is independent of the measurement used. It is expressed as a percentage of the mean (Steel and Torrie 1980). Coefficient of variation was calculated as follows:

$$CV = \frac{s}{\bar{x}} \times 100$$

The economic efficiency (cost) of each sample was calculated with the formula: economic efficiency of sample= (time required to complete the sample) X (cost/unit of time). Sample times for all methods were calculated according to how much time was spent executing them in the field. Sweep net sample times recorded in 1981 did not include the time spent counting the bag samples in the lab. The 1982 sweep net samples were counted in the field and counting time was included in the total sample time. The relative economic efficiency of several methods used for sampling insects were estimated using this same formula (Rudd and Jensen 1977). In the final analysis the sample size which combined the lowest (s/x) ratio, the lowest CV and the lowest cost was considered the best.

RESULTS

1981 Precision Tests

Table 8 summarizes results from the 1981 precision tests. In tests with various sizes of sweep samples, the 80-sweep sample had the lowest ratio in 3 tests and was second lowest in the rest. Second in the ranking order of ratios was the 10-ft sample which was slightly less precise than the 80-sweep sample. In all the sample sizes tested except the 20 and 80-sweep, ratios increased after the first test. The 80-sweep sample was the only sample size whose largest ratio occurred on the first test day. The number of TPB collected in all samples peaked during the August 3 and 13 tests and the ratios of the 80-sweep samples were lower during this time than on the first testing day in which the least number of TPB was collected. Highest ratios recorded on the August 3 and 13 tests were the 50 and 60-sweep samples. Visual counts of TPB per 8-min had the lowest ratio in both tests compared to the other sample sizes. Consistent with the results from the sweep net tests, numbers of TPB counted with the visual count per time samples peaked in the August 3 and 13 tests. The lowest ratios on these dates were recorded with the 8-min sample while the 1-min sample was second. Highest ratios recorded on these 2 dates were recorded with the 4-min sample. No TPB were observed during the July and September tests with any of these sample sizes. Dry bean plants were in the vegetative stages of growth during the July tests in both fields and in late reproductive (senescence) stages during the September tests. Results from the visual count per distance of row samples indicate that the 80-ft sample had the lowest ratios during the August and September tests and the 10-ft sample had the lowest ratios during the July

Table 8. Results from the 1981 precision test.

Sample	N	July 10	July 12	Aug 3	Aug 13	Sept 1	Sept 11	Rank
<u>Sweep Net (sweeps)</u>								
10	68	1.000*	0.000	1.115	1.008*	1.070	1.238	2
20	56	1.563	0.000	1.634	1.611	1.543	1.254	3
30	48	1.566	0.000	2.513	2.607	1.877	1.696	4
40	40	1.568	0.000	2.987	2.838	2.420	2.037	7
50	32	1.558	0.000	3.223	2.840	2.487	2.108	8
60	24	1.563	0.000	3.014	3.003	2.367	1.977	6
70	16	1.549	0.000	2.355	2.398	1.895	1.748	5
80	8	1.414	0.000	0.937*	1.216	1.045	1.195*	1
<u>Visual Count per Time (minutes)</u>								
1	64	0.000	0.000	1.120	0.933	0.000	0.000	2
2	55	0.000	0.000	1.503	1.179	0.000	0.000	3
3	48	0.000	0.000	1.713	1.267	0.000	0.000	4
4	40	0.000	0.000	1.885	1.331	0.000	0.000	5
5	32	0.000	0.000	1.840	1.255	0.000	0.000	4
6	24	0.000	0.000	1.587	1.096	0.000	0.000	2
7	16	0.000	0.000	1.264	1.915	0.000	0.000	3
8	8	0.000	0.000	0.816*	0.678*	0.000	0.000	1
<u>Visual Count per Distance (feet)</u>								
10	64	0.046*	0.978*	1.102	1.769	3.265	0.000	2
20	56	1.360	1.247	1.522	1.917	1.394	0.000	3
30	48	1.351	1.367	1.733	2.456	1.397	0.000	4
40	40	1.346	1.346	2.004	2.968	1.400	0.000	5
50	32	1.328	1.328	2.141	3.151	1.414	0.000	7
60	24	1.546	1.546	2.030	2.737	1.388	0.000	6
70	16	1.701	1.701	1.569	2.194	1.391	0.000	5
80	8	1.215	1.215	0.904*	1.506*	1.000*	0.000	1

* Denotes sample with the lowest ratio.

test. Numbers of TPB observed with the visual count per distance of row samples were highest during the August tests at which time the dry bean plant was in flower. Lowest ratios during the August tests were recorded with the 80-ft sample while the highest ratios were recorded with the 50-ft sample. No TPB were observed with any of the samples on the September 11 test.

Results of the ratios (s/x) and CV's are outlined in Table 9. It is evident from the 1981 results the sample standard deviations exceeded the sample means for the majority of the samples. The largest sample sizes of each method consistently had the lowest or second lowest CV compared to the other samples particularly when the largest numbers of TPB were recorded.

The economic efficiency of each sample size was expressed on a cost per sample basis (Table 10). Sweep net samples incur the least cost per sample compared to the other methods. In comparing the cost of the samples with the lowest ratios for each method (i.e. 80-ft, 80-sweeps, 8-min), the sweep net samples were the cheapest while the visual count per distance of row cost much more than the other 2 sample sizes. Sample times for the visual counts per time and sweep net samples were more consistent throughout the 6 tests than the visual count per distance of row samples. Sample times of the visual count per distance of row method were longer when more TPB were observed in the field unlike the other 2 methods.

1982 Precision Tests

The 1982 tests consisted of several sample sizes used in the 1981 tests as well as a few new additions. Dry bean plants were in a late vegetative stage (V7) of development when the precision tests were started. Peak numbers of TPB were recorded during the August 13 test. On this date the lowest ratios recorded by: 100-sweep, 16-min and 249-ft samples respectively (Table 11). These sample

Table 9. Coefficients of variability (CV) calculated for every sample taken during the 1981 precision tests.

Sample size	N	July 10	July 12	Aug 3	Aug 13	Sept 1	Sept 11	Rank
Sweep Net (sweep net)								
10	64	100.0*	0.000	111.5	100.8*	107.0	123.8	2
20	56	156.3	0.000	163.4	161.1	154.3	125.4	3
30	48	156.6	0.000	251.3	260.7	187.7	169.6	4
40	40	156.8	0.000	298.7	283.8	242.0	203.7	7
50	32	155.8	0.000	322.3	284.0	248.7	210.8	8
60	24	156.3	0.000	301.4	300.3	236.7	197.7	6
70	16	154.9	0.000	235.5	239.8	189.5	174.8	5
80	8	141.4	0.000	93.7*	121.6	104.5*	119.5*	1
Visual Count per Time (minutes)								
1	64	0.000	0.000	112.0	93.3	0.000	0.000	2
2	56	0.000	0.000	150.3	117.9	0.000	0.000	3
3	48	0.000	0.000	171.3	126.7	0.000	0.000	4
4	40	0.000	0.000	188.5	133.1	0.000	0.000	5
5	32	0.000	0.000	184.0	125.5	0.000	0.000	4
6	24	0.000	0.000	158.7	109.6	0.000	0.000	2
7	16	0.000	0.000	126.4	91.5	0.000	0.000	3
8	8	0.000	0.000	81.6*	67.8*	0.000	0.000	1
Visual Count per Distance of Row (feet)								
10	64	4.6*	97.8*	110.2	175.9	326.5	0.000	2
20	56	136.0	124.7	152.2	191.7	139.4	0.000	3
30	48	135.1	136.7	173.3	245.8	139.7	0.000	4
40	40	134.6	134.6	200.4	296.8	140.0	0.000	5
50	32	132.8	132.8	214.1	315.1	141.4	0.000	7
60	24	154.6	154.6	203.0	273.7	138.8	0.000	6
70	16	170.1	170.1	156.9	219.4	139.1	0.000	5
80	8	121.5	121.5	90.4*	150.6*	100.0*	0.000	1

* Denotes sample with the lowest CV.

Table 10. Economic efficiency of each sample size was calculated using the formula (sample time x cost/time). A \$0.083/minute cost was used because CCMX scouts received an average wage of \$5.00/hour in 1985.

Sample size	July 10 (min)	July 12 (min)	Aug 3 (min)	Aug 13 (min)	Sept 1 (min)	Sept 11 (min)	$\bar{x}$ (min)	cost/sample (\$)
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Sweep Net (sweeps)

10	0.75	0.75	0.67	0.63	0.52	0.49	0.63	0.52
20	1.52	1.49	1.36	1.28	1.08	0.99	1.28	0.106
30	2.28	2.64	2.05	2.01	1.59	1.49	2.01	0.166
40	3.05	2.97	2.73	2.55	2.11	1.89	2.55	0.211
50	3.91	3.76	3.42	3.16	2.70	2.03	3.16	0.262
60	4.56	4.46	3.96	3.76	3.38	2.45	3.76	0.312
70	5.31	5.34	4.76	4.53	3.79	3.48	4.53	0.373
80	6.05	6.06	5.43	5.16	4.32	3.96	5.16	0.428

Visual Count per Time (minutes)

1	0.083
2	0.166
3	0.249
4	0.332
5	0.415
6	0.498
7	0.581
8	0.664

Visual Count per Distance of Row (feet)

10	1.21	1.21	3.05	2.86	2.52	3.37	2.37	0.196
20	2.12	2.42	6.00	5.75	4.98	7.42	4.78	0.396
30	3.68	3.67	9.08	8.60	8.72	10.22	7.32	0.608
40	4.85	4.88	12.29	11.53	10.15	13.79	9.58	0.795
50	6.02	6.30	15.75	14.15	12.66	17.89	12.12	1.000
60	7.30	7.35	18.32	16.39	14.94	20.54	14.14	1.170
70	6.98	8.57	21.13	20.13	17.68	23.82	17.80	1.470
80	9.59	9.75	24.42	22.90	20.18	26.97	18.96	1.579

Table 11. Results from the 1982 precision tests.

Sample	N	July 26	Aug 13	Aug 22	Rank
<u>Sweep Net (adults)</u>					
10	5	1.478	1.362	1.350	4
20	5	0.814	0.900	0.370*	3
80	5	0.353*	0.893	0.638	2
100	5	0.501	0.625*	0.389	1
<u>Sweep Net (nymphs)</u>					
10	5	2.200	2.233	2.233	4
20	5	1.037	2.200	2.200	3
80	5	0.695	0.743	0.666	2
100	5	0.462*	0.724*	0.091*	1
<u>Visual Count per Time (minutes)</u>					
1	5	2.230	1.625	2.230	3
8	5	1.483	1.483	2.230	2
16	5	0.957*	1.350*	0.900*	1
<u>Visual Count per Distance of Row (feet)</u>					
10	5	1.730	2.230	2.200	4
20	5	0.691	1.410	1.350	3
80	5	0.837	1.006	0.790	2
249	5	0.427*	0.482*	0.500*	1

* Denotes sample with the lowest ratio.

sizes constitute the new additions to the sampling regime used in 1982. In all 3 methods the largest sample sizes had the lowest average ranking and the smallest sample sizes had the highest average ranking. Unlike the 1981 tests, separate sweep net results were recorded for TPB adults and nymphs. Results indicate the 100-sweep sample had the lowest ratio in all 3 tests for collecting TPB nymphs. Other sample sizes that had the lowest ratio in all 3 tests for their respective methods were the 16-min and 249-ft samples. The 100 and 80-sweep samples had nearly the same ratios in tests for collecting TPB adults. Although the sample sizes which had the lowest average ranking in the 1981 tests did not duplicate their ranking in the 1982 tests, their ratios were actually lower in the 1982 tests. A noticeable difference in the 1982 tests compared to the 1981 tests was the absence of zeroes. Tarnished plant bug adults and nymphs were collected in greater numbers in the 1982 tests compared to the 1981 tests which may have affected the precision of the sample sizes. Sample sizes which showed an increase in their ratios from 1981 to 1982 were the 10-sweep, 1-min and 10-ft samples.

Results from the CV calculations for the 1982 tests show an overall decrease in percentage of variability in the sweep net samples and visual counts per distance of row samples with the exception of the 10-sweep and 10-ft samples (Table 12). Higher CV's were reported in the visual count per time samples during the 1982 tests than in the 1981 tests. The 20 and 80-sweep samples had considerably lower CV's in 1982 than in 1981.

Economic efficiency calculations for the 1982 samples indicate sweep net samples take less time and cost less to execute than the other 2 methods (Table 13). In comparing the cost of the sample sizes with the lowest ratios for each method, a 100-sweep sample costs less than an 80-ft or 8-min sample. Consistent with results from the 1981 test, visual count per distance of row

Table 12. Coefficients of variability (CV) calculated for every sample taken during the 1982 precision tests.

Sample size	N	July 26	Aug 13	Aug 22	Rank
Sweep Net (adults)					
10	5	147.8	136.2	135.0	4
20	5	81.4	90.0	37.0*	3
80	5	35.3*	89.3	63.8	2
100	5	50.1	62.6*	38.9	1
Sweep Net (nymphs)					
10	5	220.0	223.3	223.3	4
20	5	103.7	220.0	220.0	3
80	5	69.5	74.3	66.6	2
100	5	46.2*	72.4*	9.1*	1
Visual Count per Time (minutes)					
1	5	223.0	162.5	223.0	3
8	5	148.3	148.3	223.0	2
16	5	95.7*	135.0*	90.0*	1
Visual Count per Distance of Row (feet)					
10	5	173.0	223.0	220.0	4
20	5	69.1	141.0	135.0	3
80	5	83.7	100.6	79.0	2
249	5	47.2*	48.2*	50.0*	1

* Denotes sample with the lowest CV.

Table 13. 1982 results of economic efficiency calculations for each sample size.

Sample size	July 26 (min)	Aug 13 (min)	Aug 22 (min)	$\bar{x}$ (min)	cost/sample (\$)
Sweep Net (sweeps)					
10	1.01	0.73	0.59	0.77	0.064
20	1.37	1.20	0.91	1.16	0.096
80	4.74	4.49	4.03	4.42	0.367
100	4.84	6.02	6.21	5.69	0.472
Visual Count per Time (minutes)					
1					0.083
8					0.664
16					1.320
Visual Count per Distance of Row (feet)					
10	0.77	0.91	0.82	0.83	0.069
20	1.67	2.01	1.49	1.72	0.143
80	5.68	6.96	7.82	6.82	0.566
100	22.88	26.29	23.20	24.12	2.000

sample times were longer in the field (August 13 test). Sweep net sample times were slightly different in the 10, 20, and 80-sweep samples recorded in 1982 compared to 1981. However, considerably less time was required to execute the visual per distance of row samples in 1982 compared to 1981. Sample times were 3 to 4 times longer in the 1981 tests and yet the ratios were higher in 1981 compared to 1982. The cost calculated for the 1982 80-ft sample was \$1.00 less than its 1981 version. It is evident from the cost analyses the rate at which the sampler progressed along the row was more rapid in the 1982 tests than in the 1981 tests.

1981 Accuracy Tests

In the 1981 comparisons of the MSE from the 4 methods, the visual counts per distance of row were less divergent from the absolute counts compared to the other methods (Table 14). Sampling done in early to late August recorded the greatest number of TPB present in the field and the visual counts per distance of row were the most accurate during this period. On days when few insects were collected such as the first and last weeks of sampling, the sweep net method proved to be the more effective in collecting insects.

Calibration results indicate the visual count per distance of row had the largest (b) value for the 2 fields in 1981. The data were transformed using the common logarithm transformation in order to homogenize the variances.

1982 Accuracy Tests

Results from the 1982 comparisons indicate the sweep net method was the most accurate in 4 out of 5 sampling days. The visual count per 80-ft of row method was clearly the least accurate method during the August tests. In the 1982 calibration tests the sweep net method had the largest (b) value. A

Table 14. Results from 1981 and 1982 comparisons of the mean square error (MSE) of the absolute count to the (MSE) of the various sample methods.

Tyler Rd. Field 1981				Crapo Rd. Field 1981				Collins Rd. Field 1982			
Date	40 sweeps	4 min	40 feet	Date	40 sweeps	4 min	40 feet	Date	40 sweeps	4 min	40 feet
July				July				July			
31*	0.63	0.00	0.67	21*	0.91	0.00	0.00	21*	0.44	1.42	0.00
Aug				24	0.42	0.00	0.30	30*	1.30	1.39	0.30
7	0.19	2.21	0.46	27	2.59	0.00	1.02	Aug			
11	0.29	1.41	0.32	31	0.00	0.77	0.00	4	1.15	1.41	2.20
14	0.57	0.98	0.33	Aug				10*	0.52	1.23	2.56
17*	1.03	0.55	0.35	4	0.80	0.77	0.80	26*	0.73	0.76	2.37
22*	1.03	1.28	0.46	7	0.37	0.00	0.21				
29*	0.66	0.00	0.10	10*	1.67	1.63	0.91				
Sept				20	0.83	0.54	0.43				
7	0.74	0.00	0.00	23*	1.56	0.81	1.09				
				26*	1.50	2.01	1.02				
				31	1.97	0.99	0.57				
				Sept							
				8*	0.95	0.00	0.00				
				23*	0.91	0.00	0.00				

*Sample variances are homogenous according to Bartlett's test (critical Level .80) (Steel and Torrie 1980).

regression analysis of sweep net collections of nymphs on absolute counts of nymphs was conducted for the 1982 data. The (b) value for the analysis was negative.

DISCUSSION

The difference between 1981 and 1982 results may reflect the increased precision in the methods used in 1982 over the 1981 methods. Both the visual count per distance of row and the sweep net methods have proven they were more effective sampling methods than the visual count per time method based on the number of zero counts recorded with the time method. In evaluating the accuracy of sample estimates from the sweep net and distance methods, sampling conditions may dictate which is most accurate to use. In 1981 during the period when peak numbers of TPB were collected, the most accurate method was the visual count per distance of row. During periods of low infestation, visual counts were useless and were less accurate than the sweep net method. Transformation of the data was necessary because the sample variances were heterogenous according to Bartlett's test (critical level at $<.05$). The common logarithm transformation proved to be the transformation that homogenized sample variances from the greatest number of sample days. Low infestation levels in the 1981 fields particularly, and the differences in the effectiveness of the sampling methods resulted in many zero counts for the visual methods while sweep net samples were not often empty. The change in infestation levels may have rendered the common logarithm transformation ineffective in homogenizing sample variances. On the contrary, the common logarithm effectively homogenized the sample variances from the 1982 data. When data consists of zero counts as in the 1981 data, then the common logarithm transformation does not homogenize the sample variances.

The calibration results coincided with the comparison tests in that the visual count per distance of row method appeared to be most accurate in 1981 while the sweep net method was most accurate in 1982 (Table 15). Visual counts per time were the least accurate in both years. The decrease in sample CV's from 1981 to 1982 can be attributed to 2 factors. The first was the improvement in the technique of the sampler during the 1982 tests. All 3 methods were executed the same in both years and the same sampler was used in both years. The second factor was the higher TPB population level in the 1982 field compared to the 1981 fields. The 1982 test area was bordered by alfalfa fields on 3 sides from which TPB migrated into the test area. In 1981 the test areas were surrounded by corn fields and dry bean fields which had very low TPB infestation levels. Several abiotic factors were found to affect the performance of the visual count per distance of row and sweep net methods. On windy days, visual counting was disrupted, whereas sweep net samples continued to collect bugs. Early morning hours, particularly when heavy dew was present on the plants, were not suitable times for walking through fields or sweeping with a net. Hot, sunny days were suited for visual counts because TPB were actively flying around and were spotted whereas the sweep net method was restricted to collecting only TPB on the plants.

In terms of precision, the largest sample sizes used in each test proved to be the most precise. These results were expected because variability among samples can be reduced by increasing either the sample size or the number of samples taken. Although the 100-sweep sample was the most precise sample size in 1982, overall test results show the 80-sweep samples were very comparable to the 100-sweep sample. The 10-sweep sample was more precise during 1981 tests when population levels were low compared to 1982 when population levels were higher. Variability was higher among the 1982 sample means because less

Table 15. Calibration factors calculated from regression analysis.
 Date for each sampling method was pooled for each method.

Sampling Method	Crapo Rd.	Tyler Rd.	Collins Rd.
40 sweeps	0.5267	1.4680	
*80 sweeps			-0.7500
+80 sweeps			1.0540
4 minutes	0.4616	0.4944	
8 minutes			
40 feet	1.2189	2.7790	0.5219
80 feet			-0.1903

* Sweep collections of tarnished plant bug nymphs

+ Sweep collections of tarnished plant bug adults.

samples were taken compared to 1981 (8 replicates in 1981, 5 replicates in 1982), and because of the higher TPB levels in the 1982 test area. Precision of sampling for nymphs was higher when 80 or 100-sweeps samples were used rather than 10 or 20-sweeps. Tarnished plant bug nymphs do not disperse from the area in which they hatched until reaching full maturity (wing development). They tend to exhibit a "clumped" distribution which affects the sample results since small sample sizes have a higher probability of missing the clumps of TPB nymphs than do larger sample sizes. It is quite possible that the 10 and 20-sweep samples, the 10 and 20-ft samples as well as all the visual counts per time samples missed the clumps, while the 80 and 100-sweep samples, the 80 and 249-ft samples did not. Of the visual counting methods, only the distance of row method was comparable to the sweep net method. Visual count per time samples were less accurate and precise than either of the other methods. Eighty ft samples were comparable to the 249-ft samples in precision while requiring 1/4 of the time needed for the larger sample. It was evident from the different results of the 2 visual counting methods that standing in a stationary position for any length of time was an inferior sampling method and that a visual count made while walking through the field was more effective. In all methods it is evident that increasing the sample size likewise increases the precision. However, time and money must be figured into the sampling plan and is quite important when deciding to take large, time consuming samples or short, efficient samples. The sweep net samples were consistently lower in cost than the other methods. Of the visual count per distance of row sample sizes, 80 -ft samples were the most comparable to the most precise sweep net sample in terms of cost and precision. The best methods appear to be the 100 and 80-sweep samples with the visual count per 80-ft of row being slightly more costly.

ABSTRACT

ECONOMIC INJURY LEVELS FOR TARNISHED PLANT BUG ON DRY BEANS IN MICHIGAN

By

Anthony W. May

Economic injury levels were to be calculated for TPB on Michigan dry beans using damage-yield information from this study. Tarnished plant bugs were caged on dry bean plants to measure the effect their feeding had on yield. A regression equation would be used to calculate threshold levels. Data from the damage-yield experiments were insignificant consequently no economic injury levels were determined.

INTRODUCTION

Since insecticide sprays are the only method available for TPB control in Michigan dry beans, it is of paramount importance for growers to know when and when not to spray. A guideline used extensively in commercial agriculture to make spray decisions is an economic injury level. An economic injury level (EIL) is defined by Stone and Pedigo (1972) as the lowest population density that will cause economic damage. Stern (1966) defines economic damage as the amount of damage which causes a greater monetary loss than is spent on control treatments (i.e. pesticides or biocontrol agents). Economic injury levels are dynamic because market prices for the crop and cost of control measures are variable. Included in the calculation of an EIL for dry beans are the current prices for: seed, insecticide and its application. By knowing the (EIL) for TPB, growers can determine the proper time for application and thus increase the effectiveness of their control program. Without this information, growers resort to the practice of applying chemicals; as "insurance" against crop loss or, after a substantial number of insects or damaged plants are seen. Several consequences of this practice are: money wasted on ill-timed applications, a resurgence of the treated species necessitating additional applications, potential contamination of the environment, and the build up of resistance in the insect to the insecticides.

Essential to the development of an EIL for a pest on an economic crop is understanding: the nature of damage by the pest, yield of the crop, and the relationship between these factors and pest density (Broersma and Luckman 1970, Chiang et al. 1960, Khattat 1978, Scales and Fuhr 1968). In his work with

beans (Khattat 1978), Khattat used regression analysis to show a linear relationship existed between density (insects/plant) and yield. Information gathered from Khattat's experiments was used in estimating an EIL for TPB on green beans in Canada. Presently, no such information is available for TPB on dry beans in Michigan.

The nature of TPB damage to dry beans as well as yield of dry beans are well documented. There is a need however, for information on the effect varying densities of TPB have on the yield of dry bean plants. Previous studies of TPB damage to beans involved caging various densities of the insect on single plants and then recording yield data from the plants (Broersma and Luckman 1970, Khattat and Stewart 1975, McEwen and Hervey 1960, Scott 1970, Stewart and Khattat 1980). Several greenhouse and field experiments were conducted in 1981, in which various densities of TPB (0, 1, 2, 4, 16/plant), were caged on dry bean plants. The following yield data was recorded on a per plant basis: number of seeds produced, percentage of seeds damaged, number of damaged seeds, and weight of seeds.

The objective of this study was to gain information on the effect various densities of TPB have on yield of dry bean plants and to estimate an EIL for this pest.

MATERIALS AND METHODS

Damage experiments were conducted in the Cereal Leaf Beetle greenhouse on the Michigan State University campus, and in a dry bean field in Gratiot County, Michigan (T10N,R2W,Sec.22) during 1981. Dry bean plants used in these experiments; Phaseolus vulgaris L. var. Sanilac, were of the same certified seed stock. Adult TPB were kept on the plants for a period of 7 days in both greenhouse and field experiments.

Greenhouse Experiments

Plants grown from certified seed were maintained under the following conditions: 80°F $\pm$ 5°F, 15 hours of daylight per day, 80-90% RH, watered regularly and contained in 6 in diameter clay pots filled with sterilized potting soil. Test plants were selected for homogenous height and development and then thinned to 1 per pot. Twenty cages made of aluminum wire cloth (18 in X 16 in mesh), shaped into cylinders (24 in X 5 3/4 in), with 5 1/2 in diameter clear plastic petri dishes enclosing the tops, were used in these experiments (Figure 4). The sides of the cylinders were attached with staples and hot glue. All TPB used in the greenhouse studies were reared from a laboratory culture. Two experiments were conducted in 1981; the first began July 17 and ended July 24, and the second began July 30 and ended August 6. In the first experiment, the cages were placed over the plants when 3 trifoliate leaves were fully formed. In the second experiment, cages were placed over the plants 3 full days after first flower. The reasons for conducting the experiments during these development stages of the plants are: 1) to determine if TPB damage to young plants reduces crop yield and quality and retards normal plant growth, 2) by waiting until 3 days



Figure 4. Cylinder cages used in greenhouse density-yield experiments.

after all plants had flowered, the insects would be confined to the plants during flowering and small pod stages. Lygus bugs damage to beans has been shown to be most severe during these stages (McEwen and Hervey 1960, Stewart and Khattat 1980).

Field Experiments

Damage experiments were conducted in 2 plots (19 ft X 40 ft), within a 20 acre field of Sanilac variety dry beans. The test plots were located on the east edge of the field, approximately 40 ft from the border.

Cultural practices- the beans were planted June 26, in 28 in rows at a density of 22 beans/m²; weed control consisted of a pre-emergence band application of Amiben (herbicide) at a rate of 1 qt/A at planting; beans were cultivated 3 and 5 weeks after planting. Twenty cages were used in each field experiment. Each cage (3 ft X 2 ft X 2 ft) consisted of a wood frame (1 in X 1/2 ft), covered with Saran Mesh (52 X 52 per in). The screening was held in place by heavy duty staples. The cages are shown in Figure 5. Test plants were selected predominantly for homogenous development with height being a lesser factor because of the vine characteristics exhibited by this variety of bean. Groups of plants were selected and thinned to 5/cage. Each cage covered 5 plants in a single row and cages were spaced at regular intervals.

Two damage experiments were conducted in the field in 1981; the first began August 7 and ended August 14; the second began August 20 and ended August 27. Adult TPB used in the experiments were reared from a laboratory culture and collected from alfalfa fields. Approximately 100 adult TPB were needed to complete the second experiment and these insects were collected from alfalfa fields on campus. Unlike the greenhouse experiment in which dead TPB were replaced with live ones, no replacements were made during either field



Figure 5. Cage used in field density-yield experiments.

experiment. The reason for no replacement was because it was physically impossible to determine the number of dead TPB in the cages.

At the beginning of the first experiment, approximately 10% of the plants in the field had their first flower. Flowering had been completed by the end of this experiment. This particular experiment was designed to confine TPB on the plants for the duration of the flowering stage. Yield data from this experiment could provide valuable information needed for estimating EIL. The second experiment was designed to investigate the effect TPB damage to setting pods had on crop yield. Plants were in the small pod stage (1 in X 1 1/2 in) when the experiment began, and were in the pod-fill stage (2 1/2 in to 4 in, with seeds discernible) at its completion. Yield data from this experiment can also provide information necessary in estimating EIL.

In both greenhouse and field experiments, cages were removed after 7 days and the test plants were allowed to mature. Beans were harvested, thrashed and yield data recorded. Yield data from both experiments were analyzed using the analysis of variance and means were compared using Duncan's Multiple Range Test.

RESULTS

Greenhouse Experiments

Results from the first and second experiments are summarized in Table 16. Analysis of variance showed that TPB did not have a significant effect on: plant height, number of pods set per plant, number of beans produced per plant, and number of stings per plant in both experiments ($p < .05$). Tarnished plant bugs died off quickly in some cages and were replaced with live bugs. Cages were checked daily during the experiment and restocking of cages was done within hours after detecting dead TPB.

Field Experiments

Results from both field experiments failed to show any correlation between plant damage and TPB density (Table 17). According to the analysis of variance, TPB density did not have a significant effect on the number of damaged seeds per 5 plants or on the average weight of seeds produced by the test plants ($p < .05$). Unlike the greenhouse experiments, no restocking was done to the field cages. It is the author's opinion that a number of TPB placed in the cages perished within a few days after the start of the experiments but the exact numbers are unknown.

Table 16. Greenhouse experiments conducted in the CLB greenhouse, on the MSU campus.

Greenhouse Experiment No.1							
Average Plant Height (inch)				Average/Plant			
number TPB/plant	before	after	height	number pods set	number beans	weight of beans (gr)	number stings
0	8 1/4	20 3/8	12 1/8	2.00	2.75	0.368	0
1	8 1/4	20 3/4	12 1/2	2.00	2.00	0.268	0
2	8	18	10	1.25	2.75	0.368	0
4	8 1/2	17 3/8	8 7/8	1.25	2.76	0.369	0
16	9 1/2	13 7/8	4 5/8	1.75	2.75	0.368	0

Greenhouse Experiment No. 2							
0	10 1/4	19 3/4	9 1/2	1.50	3.00	0.401	0
1	9 7/8	18	8 1/8	1.75	3.00	0.401	0
2	9 1/2	17 3/8	7 7/8	1.50	2.75	0.368	0
4	8 7/8	19 1/8	11	1.50	2.00	0.268	0
16	10 1/2	19 1/2	9	1.75	2.00	0.268	0

Table 17. Field experiments conducted in the Crapo Rd. field on August 7 and 31, 1981. Damaged beans refers to beans with blemishes, pits, stings and other types of damage.

Field Experiment No. 1				
Average Per Cage			Average Per Cage	
number of TPB	number of beans	weight of beans (gr)	number of damaged beans	% of total beans damaged
0	228	30.85	2.50	1.096
5	224	30.59	3.00	1.339
10	230	31.14	2.50	1.086
20	246	32.23	2.00	0.813
80	250	33.03	2.50	1.000

Field Experiment No. 2				
0	223	30.68	2.75	1.233
5	221	28.99	2.75	1.244
10	239	32.57	3.00	1.255
20	328	43.19	2.25	0.685
80	234	30.63	3.00	1.282

DISCUSSION

The failure of these experiments to provide significant results may be attributed to the fact that the insects had not been feeding on growing bean plants prior to the experiments. Tarnished plant bugs obtained from the laboratory culture were reared on fresh bean pods and may have found the bean plants unsatisfactory food sources. Another possibility was the inadequate size of the greenhouse and field cages. The cages may have been too large and did not effectively restrict the insect's movements to the immediate area around the plants. The tendency of this particular insect to perish after experiencing stress of various kinds may also explain why the field results were not significant. High rates of mortality occurred among groups of TPB aspirated from rearing containers to be used in the cage experiments and the rapid dying off of TPB after they were placed in greenhouse cages suggest the possibility that this insect is adversely affected by being caged. Similar results with TPB were recorded by Stewart and Khattat (1980) when they tried to cage these insects on bean plants.

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