DEVELOPMENT OF ECONOMIC THRESHOLDS FOR SEMILOOPERS (LEPIDOPTERA: NOCTUIDAE) ON FOUR SOYBEAN CULTIVARS IN ZIMBABWE.

By

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Dev. of ET for Semiloopers (Lepidop.: Noct.) on 4 Soy. Cult. in Zimb.

ABSTRACT

M.Sc. Renée Lapointe ENTOMOLOGY

DEVELOPMENT OF ECONOMIC THRESHOLDS FOR SEMILOOPERS (LEPIDOPTERA: NOCTUIDAE) ON FOUR SOYBEAN CULTIVARS IN ZIMBABWE.

Soybean leaf consumption for the most common semilooper species, Trichoplusia orichalcea (F.) was established in the laboratory using a leaf area meter. The total consumption per larva was 120,85 cm^2. The yield reduction of four soybean cultivars [Glycine max (L.) Merrill] being Duiker, Gazelle, Roan and SCS1 was measured in relation to different levels of defoliation. The defoliation was induced manually singly or sequentially over three different growth stages.

At soybean maturity, counts of pods per plant, number of seeds per plant, weight per 100 seeds and weight of seeds per plant were obtained. Yields were converted to a percentage of yield and linear regressions fitted to the relationship between percentage yield and defoliation. The percentage yield was influenced by the cultivars, the levels of defoliation, and the timing of defoliation.

The most critical growth stage for defoliation was the seed development stage, but the differences between them were small and not significant. SCS1 was the most resistant cultivar to defoliation, while Duiker was the most susceptible to single defoliation.

The economic thresholds were determined for the soybean ıltivars demonstrating significant linear relations between ercentage yield and single defoliation. Based on three i ecticides and two application methods, the economic thresholds were determined at the flowering stage for Duiker, at pod development stage for Duiker and Roan and at the elopment stage for Duiker, Gazelle, Roan, and SCS1 The numbers of semilooper caterpillars per metre of ed to reach the economic thresholds, are generally ighe an the natural levels of infestation.

RESUME

M.Sc. Renée Lapointe ENTOMOLOGIE

DEVELOPPEMENT DES SEUILS ECONOMIQUES DES FAUSSE-ARPENTEUSES (LEPIDOPTERES: NOCTUIDAE) POUR QUATRE CULTIVARS DE SOYA AU ZIMBABWE.

La consommation de feuilles de soya fut établie en laboratoire à l'aide d'un plannimètre, pour l'espèce Trichoplusia orichalcea (F.). La consommation totale par larve fut de 120.85 cm^2. La réduction de récolte résultant de différents niveaux de défoliation, fut déterminé pour quatre cultivars de soya [Glycine max (L.) Merrill.), soit Duiker, Gazelle, Roan et SCS1. Les défoliations furent produites de façon manuelle, simple où séquentielle lors de trois stades de croissance du soya.

Le nombre de cosses par plant, de fêves par plant, le poids de 100 fêves, et le poids des fêves par plant fut obtenu à la récolte. La récolte fut convertie en pourcentage de récolte et les régressions linéaires ont déterminé les relations entre le pourcentage de récolte et de défoliation. Le pourcentage de récolte fut influencé par les cultivars, les niveaux de défoliation et les périodes de défoliation.

Le stade de développement des fêves fut le plus susceptible à la défoliation. Par contre, les différences entre les stades de croissance furent petites et non significatives. SCS1 s'est révélé comme étant le cultivar le plus résistant à la défoliation, alors que Duiker fut le plus

susceptible aux défoliations simples.

Les seuils économiques furent déterminés pour les cultivars ayant démontré une relation linéaire significative entre le pourcentage de récolte et le pourcentage de défoliations simples. Déterminés pour trois insecticides et deux méthodes d'applications, les seuils économiques furent calculés au stade de floraison pour Duiker, au stade de développement des cosses pour Duiker et Roan, et au stade de développement des fêves pour Duiker, Gazelle, Roan et SCS1. Le nombre de larves par mètre de rangée correspondant aux seuils économiques est généralement plus élevé que les niveaux d'infestations naturelles.

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1. INTRODUCTION

Within 20 years, soybean world production has doubled (FAO 1975, 1989). Its popularity has increased due to the introduction of new cultivars which are better adapted to the growing conditions. Not to be underestimated, is the greater understanding of its extremely wide range of uses, which also helped to expand the popularity of the soybean crop. Zimbabwe's production for the 1989/90 season totalled 104 500 tonnes. The Commercial Oilseeds Producers Association (COPA) is aiming for a production of 150 000 tonnes by 1993. This would meet the local demand for oil and meal. For now, soya provides about 40 percent of Zimbabwe's vegetable oil requirement (Syme 1990).

Being relatively new to Zimbabwe, soybean supports few insect pest of importance. Three species of Noctuidae defoliate the soybean crop every year. The caterpillars of Trichoplusia orichalcea (Fabricus), Chrysodeixis chalcites (Esper) and C. acuta (Walker) are present in the field throughout the year, but increasingly so from January to March.

This period corresponds to the reproductive growth stages of the soybean crop. Many studies have shown that the vegetative growth stages of soybean are not susceptible to foliage damage since the plant can compensate for defoliation. On the other hand, the reproductive growth stages are more susceptible to leaf injury since the plant does not produce any more foliage in the later stages of development. The semilooper infestations, thus, coincide with the most vulnerable period for the soybean crop.

In Zimbabwe the different cultivars in use have been bred locally in order to respond to the fluctuating climatic conditions and regions. There are, therefore, many new cultivars in use, for which little information has been gathered in relation to foliar damage resistance. All three species of semilooper are naturally infected by a Nuclear Polyhedrosis Virus complex under suitable climatic conditions. Therefore most producers tend to wait for the virus to wipe out any semilooper populations, independently of the extent of the caterpillar infestation. The development of economic thresholds will permit a better understanding of the effect of the semilooper complex on these new cultivars as well as determining the level to which the non-intervention strategy is still acceptable.

The present study was undertaken to determine the economic injury levels and the economic thresholds of the semi-looper complex on Duiker, Gazelle, Roan and SCS1 soybean cultivars. These cultivars were selected for their present and future economic values as well as for their distinct growth habits. This study involved the determination of leaf-area consumption of the semilooper's caterpillars under laboratory conditions. We also studied the effect of known levels of defoliation on soybean yield. The levels of defoliation were related to the leaf-area consumption per caterpillar in order to determine the number of caterpillars required to cause known defoliation levels. This approach allowed the development of economic thresholds.

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2. LITERATURE REVIEW

2.a. NOCTUIDAE

The family Noctuidae includes the largest number of species in the order Lepidoptera (Holloway et al 1987; Janse 1939). The noctuid moths are mostly medium-sized and rather dull-coloured. The forewings are usually brownish with an inconspicuous pattern, while the hindwings are either much paler or lack the forewing's pattern, bearing simply a darker margin (Caswell 1962). The family members do not necessarily have the same appearance but their morphological structures are very similar (Janse 1939).

The Noctuids comprise species of great economical importance due to the destructive plant feeding behaviour of the larvae (Caswell 1962; Janse 1939; Schmutterer 1969). The caterpillars are usually brown or green in colour, smooth or with very few hairs and they generally pupate in the soil (Caswell 1962).

2.b. PLUSIINAE

Members of the Plusiinae subfamily are included in most lists of insect pests of importance and are widespread geographically (Smith 1978). The venation within the group is very homogenous; only the genitalia are used to separate the genera (Dufay 1970). They share similar external features such as the dorsal crest of scale on the adult thorax and anterior of abdomen, and a pale or metallic streak or stigma at the centre of the forewing (Holloway et al 1987).

In Zimbabwe, soybean damage results mainly from defoliation by Plusiinae species, namely the semiloopers; _Trichoplusia orichalcea_ (F.), _Chrysodeixis acuta_ (Wlk.), _C. chalcites_ (Esp.) (Taylor 1980). They consume considerable amounts of foliage every season, indirectly reducing the potential soybean yield (Taylor 1980).

2.c. DISTRIBUTION AND TAXONOMY

2.c.a. _Trichoplusia orichalcea_ (Fabricius)

T. orichalcea occupies a very wide territory, ranging between 60° North and 40° South. It is, however, excluded from the American continents, inhabiting the Western Palaearctic, Asia, Indonesia, Eastern Australia, New Zealand, Sub-saharan Africa territories as well as the Southern Palaearctic including a number of islands such as Comores and Madagascar (C.A.B. 1986; Dufay 1970).

Trichoplusia orichalcea was first described from India by Fabricius as _Noctua orichalcea_ in 1775. The numerous taxonomic changes gave rise to many genus synonyms [_Thysanoplusia_, _Diachrysia_ and _Plusia_ (C.A.B. 1986)] and species synonyms [_Phalaena chrysitina_ Martin, _Noctua orychalcea_ Hubner, _Noctua aurifera_ Hubner] (Poole 1989b).

T. orichalcea has also frequently been studied under various synonyms [_Thysanoplusia_ (Hill _et al_ 1987; Hill 1989), _Diachrisia_ (Turner 1978), _Diachrysia_ (Taylor 1980; Turner

1978), Plusia (Bhardwaj and Panwar 1990; Caswell 1962; Dhuri and Singh 1983; Evans 1952; Faleiro and Singh 1985; Hill and Waller 1988; Jack 1941; Mehto and Singh 1983; Rose 1963; Sardana and Verma 1986; Schmutterer 1969; Singh and Singh 1977; Singh and Singh 1987) and Phytometra (Evans 1952)].

The listed common names are numerous (C.A.B. 1986), but semilooper is by far the most frequently used common name (Hill and Waller 1988; Hutchison 1988; Sardana and Verma 1986; Singh and Taylor 1978; Taylor 1980).

2.c.b. Chrysodeixis acuta (Walker)

C. acuta is reported in Northeast and Central Africa (Schmutterer 1969), Nigeria (Singh and Taylor 1978), Uganda (Nyiira 1978), Zimbabwe (Hutchison 1988; Rose 1963; Taylor 1980; Taylor and Kunjeku 1983), as well as in India (Singh et al 1987; Singh and Singh 1987). Its distribution, however, has not yet been compiled in C.A.B.'s Institute of Entomology Distribution Maps of Pests.

It was discovered by Walker in 1858 as Plusia acuta in the Congo and in Japan as Neoplusia furihatai by Okano in 1963 (Dufay 1970; Poole 1989a). It is frequently called the green semilooper (Singh and Singh 1987; Singh et al 1987) or simply semilooper (Hutchison 1988; Singh et al 1987; Taylor 1980; Taylor and Kunjeku 1983).

2.c.c. **Chrysodeixis chalcites (Esper)**

Distributed from 55° North to 45° South, C. chalcites inhabits the Mediterranean basin, most of coastal Asia, the whole of India, Indonesia, New Zealand, Eastern Australia and extends into the Pacific as far as Easter Island (C.A.B. 1977; Holloway 1977). Furthermore, it is found in coastal West Africa, Sub-saharan Africa, Southern Africa as well as Madagascar, the Seychelles, Comores and Mauritius Islands (Dufay 1970; C.A.B. 1977).

First described as Phalaena noctua by Esper in Italy, 1789, taxonomic changes have given the genus several synonyms; Plusia, Phalaena and Noctua; and many species synonyms Phalaena noctua chalcytis Hubner, Noctua bengalensis Rossi, Noctua quaestionis Fabricius, Plusia vercillata Guenee, P. integra Walker, P. adjuncta Walker; (Poole 1989a), P. chalcites (Esp.) and Phytometra chalcites (Esp.) (C.A.B. 1977).

Many workers worldwide have used the synonyms of Plusia chalcites (Evans 1952; Holloway 1977), Chrysodeixis chalcites (Hutchison 1988; Litsinger et al 1978; Rejesus 1978; Taylor 1980; Taylor and Kunjeku 1983; Turner 1978). Common names such as semilooper (Hutchison 1988; Taylor 1980; Taylor and Kunjeku 1983); green looper caterpillar, silver Y moth (Roberts 1979) and golden twin spot (Litsinger et al 1978; Turner 1978) are used also.

Chrysodeixis chalcites is mentioned as C. eriosoma (Doubleday) or Plusia eriosoma (D.) either as a synonym or as a sister-species which would relate to the Indo-Australian and Pacific area, while C. chalcites would apply to the African and South-Western Palaearctic population (Fitton et al 1983; Holloway 1977; Roberts 1979). However Dufay (1970) does not agree with these trends of classification and Holloway et al (1987) believe that clarification is still required.

2.d. BIOLOGY AND ECOLOGY

2.d.a. Trichoplusia orichalcea (F.)

The biology of T. orichalcea (Hill et al 1987) has rarely been studied in detail, although it is frequently reported as an important pest of pulses and beans (Bhardwaj and Panwar 1990; Dhuri and Singh 1983; Evans 1952; Faleiro et al 1986; Hill et al 1987; Hutchison 1988; Sardana and Verma 1986; Taylor 1980; Taylor and Kunjeku 1983). Taylor (1980) gave a descriptive account of T. orichalcea biology as a Zimbabwean pest. It's successful establishment in New-Zealand in 1984, resulted in its biology being studied in detail by Hill et al, 1987.

This species seems to be gaining importance in pest status as earlier reports classified it as a pest of only minor importance (Caswell 1962; Jack 1941; Mehto and Singh 1983; Rose 1963; Schmutterer 1969; Turner 1978). It has changed very rapidly, even overtaking established pests with a similar niche (Hill et al 1987; Taylor 1980; Taylor and Kunjeku 1983).

2.d.a.a. Life Cycle

T. orichalcea is a multivoltine species (Taylor 1980). In Zimbabwe, two generations occur on its main host, during the rainy season (November to April) and the remainder on alternative hosts during the dry season (Hutchison 1988; Taylor 1980). Elsewhere population peaks of T. orichalcea always correspond to the rainy season or the kharif season in India (Dhuri and Singh 1983; Faleiro and Singh 1985; Faleiro et al 1986; Sardana and Verma 1986).

The eggs are laid on the underside of the leaves or on the stem of the plants (Hutchison 1988; Taylor 1980). In Zimbabwe, they hatch after an average period of 3 to 4 days (Hill et al 1987; Hutchison 1988; Taylor 1980). There are usually five instars; sometimes a sixth occurs. The first stadium is 3 days, the second 1 day, and the subsequent ones 3 days each (Taylor 1980). The pupae develop in a silken cocoon for a period of 7 to 10 days (Hutchison 1988; Taylor 1980). At room temperatures T.orichalcea moths emerge in the late morning (Lapointe unpublished data). The total generation time is 24 to 35 days (Hill et al 1987; Hutchison 1988; Taylor 1980).

The population peaks are synchronized with the mature vegetative or reproductive growth stages of beans and pulses (Dhuri and Singh 1983; Faleiro and Singh 1985; Faleiro et al 1986; Mehto and Singh 1983).

2.d.a.b. Description

The eggs of T. orichalcea are yellow or pale green, round and ridged, about 0.6 mm in diameter (Hill et al 1987; Hutchison 1988; Taylor 1980). The hatching larva is only 2 mm long and is whitish in colour except the head capsule which is black. Upon feeding on plant leaves, the body as well as the head capsule rapidly become green in colour. Short white hairs emerge from black spots on the body of T. orichalcea caterpillars, and these help distinguish it from Chrysodeixis spp. (Hill et al 1987; Hutchison 1988; Taylor 1980). The body length attained by the final instar is 35 mm long. All three semilooper caterpillar species have a looping gait created during motion by the absence of abdominal legs in the middle part of the body. There are only 3 pairs of prolegs (Hill et al 1987; Hutchison 1988; Taylor 1980).

The pupae are similar for the three species being bright green to later becoming black on the dorsal surface and green to tan on the ventral side (Lapointe unpublished data; Roberts 1979). The difference between the species being on the 3rd and 7th abdominal segment, where a triangular process from the dorsal midline protrudes on the anterior margin (Hill et al 1987). Also, T. orichalcea pupae are normally almost entirely wrapped in one or more leaves (Hill et al 1987).

The adults have olive brown forewings with a conspicuous broad L-shaped metallic gold patch covering the central and subterminal areas. The hindwings are paler straw-coloured or greyish-brown. The wing span is 35 to 40 mm (Hutchison 1988; Taylor 1980). The thorax bears the characteristic scale tufts of many Plusiinae (Hill et al 1987). The forewing's pattern and a dull orange head are unmistakable identification characters (Hill et al 1987).

2.d.a.c. Life Habits

Like many members of the subfamily Plusiinae, *T. orichalcea* is polyphagous (Caswell 1962) and defoliate a wide variety of crop plants such as apple , blackjack, cabbage, chicory, cotton, ground nuts, kidneybean, lucerne, mint, orchard grass, parsley , potato, radish, rape, ryegrass, sunflower, sunhemp, tobacco , tomato (Bhardwaj and Panwar 1990; Hill et al 1987; Schmutterer 1969; Taylor 1980). However *T. orichalcea* is considered only a minor pest in any of the previously mentioned crops. The major pest status is reserved for its effect on legumes or pulses.

For over 50 years the golden wedge moth has been a major defoliator of soybean in Africa (Jack 1941; Hutchison 1988; Taylor 1980; Taylor and Kunjeku 1983) and more recently in New Zealand (Hill et al 1987). In India, many workers have studied and reported major infestations on various pulses and beans such as black zira (Bhardwaj and Panwar 1990), chick pea (Mehto and Singh 1983), cowpea (Faleiro and Singh 1985; Faleiro et al 1986; Sardana and Verma 1986), greengram and blackgram (Dhuri and Singh 1983; Singh and Singh 1977).

2.d.b. Chrysodeixis species

The biology of C. chalcites has been studied along with other semilooper species (Hutchison 1988; Rejesus 1978; Singh et al 1987; Taylor 1980) and on its own under C. eriosoma (D.), the "New World" type. In the Philippines it is particularly serious during the vegetative growth stage of soybean (Rejesus 1978), but the period of high light trap catches in New Zealand would rather correspond to well established vegetative growth stages or to reproductive stages (Roberts 1979). The biology of C. acuta has not been studied on its own. Taylor (1980) studied the semiloopers as a group of defoliators of soybeans in Zimbabwe.

2.d.b.b. Life Cycle and Description

The two Chrysodeixis species have been studied in Zimbabwe, along with T. orichalcea (Taylor 1980). Light trap catches in New Zealand (Roberts 1979), suggest a shorter generation period in the summer than in the winter (Taylor 1980). The winter generations survive on evergreens, while the summer generations can be serious agricultural pests (Roberts 1979; Taylor 1980). An account of the life cycle and description of _C. chalcites/eriosoma_ has been given for New Zealand (Roberts 1979) and Norfolk Island (Holloway 1977).

C. chalcites/eriosoma larva spins its cocoon in leaf detritus, in a folded leaf or between two leaves within which the pupa will develop (Holloway 1977; Roberts 1979; Taylor 1980). At first the pupa is bright green, but later becomes black on the dorsal surface and green to tan on the ventral side (Roberts 1979).

The _C. chalcites_ moth is medium sized with a 19 to 20 mm wing span and has bronzy or purplish brown reflections on the forewings with two silvery white marks near the centre of each forewing. The hindwings are greyish-brown (Dufay 1970; Holloway 1977; Hutchison 1988; Taylor 1980). From the back of the thorax protrude the characteristic Plusiinae hairy tufts or crests. The female abdomen is stouter than the male's and tapers posteriorly, while the male has yellow scent brushes along the sides of the abdomen and large black brushes at the rear (Roberts 1979). The _C. acuta_ moth has dark grey-brown forewings and a silvery 8 or Y-shaped marking in the middle similar to _Trichoplusia ni_ (Hbn.) (Smutterer 1969) and to _C. chalcites_ (Dufay 1970). _C. chalcites_ has more reddish and paler colours than _C. acuta_ (Dufay 1970). Dufay also presents a key to these two species (1970).

2.d.b.c. Life Habits

C. chalcites is mostly a defoliator of horticultural and bean crops (Fitton et al 1983; Litsinger et al 1978; Rejesus 1978; Roberts 1979; Taylor 1980; Turner 1978), but sometimes flowers and fruits or pods are also eaten (Roberts 1979; Turner 1978). Roberts (1979) developed an artificial diet which is adequate for the first 4 instars, after which the caterpillars are reared on leaves of Solanaceae. C. chalcites is polyphagous and is constantly reported as a pest of leguminous species (Cameron et al 1986; Holloway 1977; Rejesus 1978; Roberts 1979; Taylor 1980; Turner 1978). It also defoliates horticultural crops such as lettuce, pumpkin (Holloway 1977), tomato (Holloway 1977; Roberts 1979; Taylor 1980), coffee, cotton, Ficus and many other garden crops (Taylor 1980).

In India, C. acuta used to be reported as a defoliator of minor importance, but is now established as a serious and regular pest, damaging foliage, flowers and pods of bean, cowpea and soybean (Singh and Taylor 1978; Singh et al 1987; Singh and Singh 1987).

In Africa, Schmutterer (1969) recorded C. acuta as a rather harmful defoliator of vegetable crops, while Nyiira (1978) mentioned it as an obvious but not serious foliage pest of bean and cowpea in Uganda. Taylor and Kunjeku (1983) recorded C. acuta as being the second most common semilooper species defoliating soybean in Zimbabwe. Canna lilies, banana, celery, cotton and maize are alternate hosts (Taylor 1980).

2.e. CONTROL

2.e.a. Chemical Control

Control recommendations date from 1978 (Rejesus 1978; Singh and Taylor 1978; Turner 1978). Turner and Rejesus (1978, 1978) recommended endosulfan 35EC to which Turner (1978) added methomyl, to control C.chalcites caterpillars. In Nigeria, C.acuta was found to be effectively controlled by endosulfan, BHC or monocrotophos at 600 g/ha (Singh and Taylor 1978). In Australia, methomyl (300g/ha) was found sufficient as a control against T. orichalcea (Turner 1978).

Hutchison (1988) did not differentiate between the three species since they all appear locally as soybean defoliators and are difficult to distinguish in field conditions. Endosulfan and monocrotophos are recommended here also; in addition to which, carbaryl, cypermethrin, dichlorvos and trichlorfon are also mentioned. However carbaryl is said not to be efficient on older caterpillars and on C. chalcites (Taylor 1980).

2.e.b. Biological Control

In Zimbabwe a naturally occurring nuclear polyhedrosis virus is recommended by Hutchison (1988) and Taylor (1980) as a control measure for the semilooper complex. COPA's Oilseed Handbook recommends collecting infected caterpillars, to extract and store the virus in the dry season and applying the viral solution in the field during early semilooper's infestation the following year. The artificial infestation needs to be carried out early enough to wipe out the semilooper's population before damage has been done (Hutchison 1988, Taylor 1980).

Fitton _et al_ (1983) mentioned the presence of ichneumonids (Hymenoptera) parasitizing two species of semiloopers. _C. chalcites_/_eriosoma_ is host to _Ctenochares bicolorus_ (L.) in New Zealand and _T. orichalcea_ is host to _C. rufithorax_ (Kriechaumer) in Kenya. Litsinger _et al_ (1978) indicated low levels of parasitism of _C. chalcites_ by unidentified larvae.

2.f. SAMPLING

Pest management cannot operate without accurate estimates of pests and acquiring quantitative information about the agroecosystems is a preliminary phase of any basic or applied work on insect-plant interactions (Ruesink and Kogan 1982).

The best classification of sampling methods was adopted by Morris (1955) where he describes absolute versus relative estimates. Basic research requires precise estimates of parameter values obtained often through absolute sampling methods, while pest management requires the rapid classification of situations into a decision category. These decisions can be reached by relative sampling methods (Ruesink and Kogan 1982).

Ruesink and Kogan (1982) and Dent (1991) interpreting from Morris (1955), state that absolute method estimates are densities per unit of land area which are directly comparable in time and space. Relative estimates are described as densities per some unit other than land area which cannot be converted to absolute estimates without a major effort to correct for insects behaviour and/or for the effect of habitat (Ruesink and Kogan 1982). Dent (1991) added that relative estimates can be regarded as being representative of the number present and which may actually reflect them, but is not a true account of the density. The decision to use either absolute or relative estimates must balance the objectives of the programme with the accuracy of the estimate required and the ease with which the estimate can be obtained (Dent 1991).

2.f.a. Absolute Estimates

Ruesink and Kogan (1982) described four approaches to the absolute methods of sampling; distance to the nearest neighbour, sampling a unit of habitat, recapture of marked individuals, and removal trapping.

Sampling a unit of habitat is by far the most favoured approach to monitoring soybean's insects. It is based on isolating a population in a known surface area after which the insects of all stages are dislodged either by fumigation or by the harvest of the whole plant (Kogan and Pitre 1980; Lee and Johnson 1990; Terry et al 1989); specimens are then taken for screening and identification. Methods such as nearest neighbour, recapture of marked individuals and removal trapping have not been adequately tested for soybean arthropods (Southwood 1978).

2.f.b. Relative Estimates

Relative estimates are obtained from catches per unit effort or by trapping. Catches per unit effort include visual or direct observations, sweep net, D-Vac or suction nets and shaking or beating methods (also called ground cloth methods). These techniques have been more developed for the soybean crop than have trapping methods (Kogan and Pitre 1980). Trapping techniques include Malaise, windowpane, pitfall, sticky and visual traps as well as traps using attractants.

2.f.c. Sampling for Semiloopers

Almost all reports of semilooper larval populations used the visual observation of whole plants as a sampling method, either for only one species or for the semilooper complex (Faleiro and Singh 1985; Faleiro et al 1986; Hill et al 1987; Hutchison 1988; Mehto and Singh 1983; Sardana and Verma 1986; Singh and Singh 1978; Singh and Singh 1987). A description of the method is found in Herzog and Todd (1980), Ruesink and Kogan (1982) and Kogan and Pitre (1980). In order to reduce the time factor, Faleiro et al adjusted the technique to observations of trifoliates as subsamples (1985; 1986).

The beating cloth technique has also been used, but with a metal tray instead of a cloth (Cameron et al 1986; Hill et al 1987) to catch larval stages of semiloopers in soybean and lucerne. First described by Boyer and Dumas (1963), the technique is well described in Kogan and Pitre (1980) and Ruesink and Kogan (1982). Except in plant lodging period, it is a precise, cheap and consistent method (Kogan and Pitre 1980). The adult moths of semiloopers have been reported from light trap catches (Hill et al 1987; Roberts 1979).

2.g. ECONOMIC THRESHOLDS

2.g.a. History and Definition

The fundamental questions asked by Pierce in 1934 about pest management have been developed through a long series of definitions and concepts. By now most entomologists agree that the answers to how many insects cause how much damage and is the damage significant, constitutes the backbone of progressive pest management (Hutchins et al 1988; Mumford and Norton 1984; Ostlie and Pedigo 1987; Pedigo et al 1986; Poston et al 1983). To help answer these questions, Stern et al (1959) defined the concept of economic threshold (ET), and it is still the most accepted form of decision rule in insect pest management (IPM) today (Hutchins et al 1988; Onstad 1987; Pedigo et al 1986). Three concepts are built into the term economic threshold (Stern et al 1959). These are:

1- the economic damage (ED); the amount of injury that will justify the cost of artificial control measures;

2- the economic injury level (EIL), the lowest pest population density that will cause economic damage;

3- the economic threshold (ET), the pest density at which control measures should be applied to prevent an increasing pest population from reaching the EIL.

Some deficiencies have been recognized with the original definition and semantics. First of all, the EIL is defined as a population, not an injury level. It is, however, noted by Pedigo et al (1986) that understood in the definition, is that a certain number of insects produce a fixed amount of injury, the pest population being a direct index of the injury level.

Perhaps the most important deficiency in Stern's concept was the lack of mathematical components definitions of the economic damage, which contributed to the delay of its application. The first calculated EIL was published over a decade later (in Pedigo et al 1986).

Criticism was levelled at the original concept's simplicity. Although it began from ecological premises by aiming for a reduction or a more efficient use of pesticides (Ostlie and Pedigo 1987; Stern et al 1959), the actual mathematical components do not take into account many environmental and sociological factors (Onstad 1987; Ostlie and Pedigo 1987). Again Pedigo et al (1986) noted that it is this very simplicity which has kept the EIL concept so popular for over 30 years. Until we have a better knowledge about pests and their effects on the agroecosystems, simple formulae for EIL are likely to be used (Onstad 1987). Because they integrate basic elements of crop management, the EIL and ET concepts are viable and dynamic (Onstad 1987; Ostlie and Pedigo 1987; Pedigo et al 1986), they vary according to crop cultivar, plant growth stages, weather, plant density, fertilizer and other factors (Dent 1991; Hutchins et al 1988; Onstad 1987).

Interpretation of the concept of ET has led to a war of semantics from which terms such as "action threshold" (Chant 1966), "control threshold" (Sylven 1968), "action level" or "inaction threshold" (Sterling 1984) and "dynamic action threshold level" (Walgenback and Wyman 1984) were used at some point in the literature and still are used (Dent 1991). This proliferation of related terms have obscured the content and philosophical orientation provided by the concepts of Stern et al (1959) (Ostlie and Pedigo 1987).

2.g.b. Mathematical Components

The mathematical component of the ET involves, in a simplified form, 4 determinants; costs of control, market value of harvested product, proportionate damage/yield loss/individual insect and the effectiveness of control (Dent 1991). However Pedigo et al (1986) split the proportionate damage per yield loss per insect determinant into injury units per insect/production unit and damage/unit injury. They also reserved the effectiveness of the control determinants for situations needing optimal reduction of the pest.

Onstad (1987) presented formulae which were based on the basic concepts of EIL and ET. However, these formulae were not restricted to linear relationships between insect density and economic loss; they calculated ET directly and also clarified the differences between EIL and ET by placing the emphasis on the temporal dynamics of agrosystems (i.e., EIL tactics are to be implemented immediately while ET changes according to situations and is not necessarily implemented immediately at time t).

The original authors (Stern et al 1959) placed the emphasis on the pest, not on the damaged host. Many authors argued that a transformation of pest numbers into injury equivalency would help in the development of EILs for multiple-species, life stages within a species, and multiple-stress situations (Hutchins et al 1988; Ostlie and Pedigo 1987; Pedigo et al 1986). Hutchins et al (1988) suggested placing the different pest species in injury-guilds which represent the same stress stimulus and affect the host physiology in the same fashion. The determination of injury-equivalents requires specific data such as species and stage specific estimates on survivorship and on potential injury as well as the determination of the desired level of risk in estimating survival (Hutchins et al 1988; Ostlie and Pedigo

1987).

Stern (1973) concluded that the concept was evolving as practical decision-making become more sophisticated. However as complexity increases it becomes difficult to implement the concept especially as the techniques required for calculations did not evolve at similar rates (Dent 1991; Onstad 1987).

2.h. ECONOMIC THRESHOLDS DETERMINATION: SOYBEAN NOCTUID DEFOLIATORS

2.h.a. Yield Loss Assessment

The determination of ETs must be timed relative to crop growth and development (Zadock 1987). This is especially true with the soybean crop, whose growth habits are divided into vegetative (V1 to Vn) and reproductive stages (R1 to R8) (Fehr et al 1971) and into determinate and indeterminate growth patterns (Hicks 1978; Shibles et al 1975).

The yield loss assessment part of ET determination is tedious and depends on the physiological categories of insect injury caused to plants. Walker (1987) describes nine periods/parts where yield can be lost; crop establishment, photosynthetic area, uptake of nutrient or water, translocation, storage organs, reproductive parts, secondary loss, spoilage and loss of quality, harvesting and processing losses. Hutchins et al (1988) and Pedigo et al (1986) group the types of attack into six physiological responses categories being; stand reduction, leaf-mass consumption, assimilate removal, water balance disruption, fruit destruction and architecture modification.

Noctuid larvae are chewing insects (Caswell 1962; Janse 1939; Schmutterer 1969) which consume leaf mass, reducing the area of photosynthetic material (Dent 1991; Hutchins et al 1988; Pedigo et al 1986; Walker 1987). The defoliation damage is easily noticeable but will not necessarily cause yield losses (Dent 1991; Luckmann and Metcalf 1982). More yield reduction will occur if reduction in photosyntate material is done prior to a redistribution of new materials to the reproductive structures (Dent 1991).

Entomologists and plant scientists have not collaborated well on the subject of plant growth analysis (Dent 1991). Nevertheless the subject of defoliation effects during the various soybean growth stages is well documented for the purpose of yield loss assessment (Fehr et al 1981; Hicks 1978; Shibles et al 1975; Talekar and Lee 1988; Thomas et al 1978). It has been shown that leaf consumption directly affects the absolute photosynthesis of the plant canopy, but has little or no effect on photosynthesis per unit of remaining leaf tissue. The various defoliator species differs only in consumption rate (Hutchins et al 1988; Pedigo et al 1986). Four main approaches are used to quantify yield losses due to pest attacks; survey of pest densities, insecticides, artificial infestation and damage simulation (Higgins et al 1984; Van

Emden 1978).

2.h.a.a. Sampling

The estimation of natural population densities is made difficult by pest mobility, sampling procedures and the fact that natural insect populations are often unpredictable, making serial replication difficult or impossible (Higgins *et al* 1984). Ideally it would, however, integrate the pest survivorship concept (Ostlie and Pedigo 1987) into the ET calculations.

2.h.a.b. Insecticides

The use of insecticides to create different levels of insect population may result in an altered potential for the surviving individuals to cause consistent damage (Higgins *et al* 1984). However it can also be used at different crop stages to remove the whole population, as Cameron *et al* (1986) have demonstrated with *Chrysodeixis eriosoma* (Doubleday).

2.h.a.c. Artificial Infestation

The artificial establishment of pests on the crop would be ideal except for the difficulty of rearing or obtaining the required insect population. Also the microenvironment might be altered by the use of cages (Higgins *et al* 1984); a description of methods is given by Beach and Todd (1988b) and Talekar *et al* (1988).

2.h.a.d. Damage Simulation

Damage simulation methods should be chosen with care, in order to mimic the attack phenology which will be as close as possible to the reality. Although it requires intense effort (Higgins et al 1984), it is also the method of choice in the standardization of damage by different insects into a common injury-guild (Hutchins et al 1988). It is the most frequent method used to produce injury; 89% of workers have simulated insect injury for soybean defoliation studies (Hutchins et al 1988). 73% described injury in terms of percentage defoliation (Hutchins et al 1988) which is also defined as the leaf mass consumption category of insect injury (Pedigo et al 1986). Apart from stand reduction and fruit destruction, the other categories would be more difficult to simulate.

Four different techniques of defoliation are used. The most common is the removal of the whole leaflet; employed by over 80% of the workers in the field (Hutchins et al 1988) and has been used consistently since the 1960's (Begum and Eden 1965; Fehr et al 1981; Ostlie and Pedigo 1985; Talekar and Lee 1988; Taylor and Kunjeku 1983; Todd and Morgan 1972; Turnipseed 1972). The second method is hole punching of leaves, where a paper punch or a cork borer is used in order to mimic insect defoliation (Hammond and Pedigo 1982; Higgins et al 1984; Ostlie and Pedigo 1985; Poston et al 1976; Talekar and Lee 1988). Talekar and Lee (1988) also documented the methods of cutting part of the leaflet either through or along the midrib.

Most of the insect simulation methods employed a single defoliation at a particular soybean growth stage (Begum and Eden 1965; Caviness and Thomas 1980; Fehr et al 1981; Taylor and Kunjeku 1983), and some compared both single and consecutive defoliations (Poston et al 1976; Talekar and Lee 1988; Thomas et al 1978; Todd and Morgan 1972; Turnipseed 1972). A few workers have simulated defoliation according to a temperature-dependent and developmental model for insects such as Green Cloverworm (Hammond et al 1979; Hammond and Pedigo 1982; Higgins et al 1984; Ostlie and Pedigo 1985) and Painted Lady (Hammond and Pedigo 1982).

Once the damage-yield loss relationship has been established, the determination of the insect-yield loss is easily found with data from leaf consumption trials (Boldt et al 1975; Waters and Barfield 1989). The defoliation assessment may be carried out from video imagery and micro computer analysis combined as an Area Analysis System (AAS) (Nolting and Edwards 1985), or with the use of a leaf area meter (Taylor and Kunjeku 1983). The latter may also be used for field measurements by calculating the difference between the undamaged leaf area, calculated from a mathematical equation adapted to soybean, and the actual defoliated area by an area integrator meter (Jensen et al 1977) or more simply by comparing the damaged plot with an insecticide-sprayed control.

2.h.b. Environmental Factors Affecting Insect Growth and Consumption

Environmental factors should also be taken into consideration when establishing ET. It has been shown that many noctuid larvae consume different amounts of soybean leaves depending on leaf position and plant age (Reynolds and Smith 1985), leaf wounding (Croxford et al 1989; Reynolds and Smith 1985), larval intensity (Pedigo et al 1977), soil water potential (Lambert and Heatherly 1991); and whether the soybean plants were reared in a greenhouse or in the field (Hammond et al 1979). But as Dent (1991) states, it would be difficult to implement these results as the techniques required for the calculations are not developed.

2.h.c. Economic Threshold for Semiloopers

Semiloopers are pests of relatively new economic importance on soybean. The ET and EIL were established by Taylor and Kunjeku (1983) in Zimbabwe. A level of about 1.5 caterpillars per plant or 30 caterpillars per meter of row at pod formation (R3) and at seed formation (R5) stages (Fehr et al 1971) is sufficient to reduce the yield significantly. This implies that it is economical to spray as soon as the semiloopers appear in the field.

More recently, Cameron et al (1986) established the ET at 22 larvae per meter of row at the R5 growth stage for Chrysodeixis eriosoma in New Zealand. The row spacing here was

45 cm, while Taylor and Kunjeku employed 75 cm, this difference can partly explain the variation in the calculation.

Although Singh and Singh (1987) did not work out the actual ET, they determined that at a level of 14.6 larvae/10 plants, it was economical to spray for Chrysodeixis acuta. However, they did not provide data on plant spacing, making it difficult to relate this study with the others.

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3. DEFOLIATION SIMULATION

3.a. MATERIALS AND METHODS

3.a.a. Field Trials

The field trials were conducted on the Agricultural Research Trust Farm (ART), Zimbabwe, over two seasons (1990/91, 1991/92). The site is 1500m above sea level at 17°43'S and 31°5'E. The soil type is red clay with an average depth of 1,5 m (pers. com., J.F.MacRobert, ART Farm).

Four commercially available soybean cultivars (Duiker, Gazelle, Roan, and SCS1) were dipped in a mixture of Rhizobium, water and sugar and were sown at approximately 300 000 seeds ha^{-1} at 0.75m rows spacing. Planting was on the 4th of December 1990 and on the 2nd of December 1991. Trials of both years were established following maize, and were on contiguous plots, 10 meters apart.

The trial was laid out in a randomized complete block design with three replications in blocks with 60 treatments (90/91) and 144 treatments (91/92). In the 1990/91 season, the plot was 80 m long X 38 m wide. It was divided in treatment plots of 2.5 m long X 3 m wide (5 rows at 75 cm spacing). Treatments were carried out on the three middle rows but yields were taken from the central meter of the middle row only. In the 1991/92 season, the plot was 84 m long X 40 m wide. The plots were 1.5 m long X 1.3 m wide (3 rows). Treatments were carried out on the middle row. Leaf area records were taken from the 5th soybean plant of the northern part of the middle row, and yield measurements were taken from the central meter of the middle row only.

The method of defoliation consisted of cutting the whole soybean leaflet or half-leaflet along the midrib with scissors (Talekar and Lee 1988). The defoliation treatments were applied when most of the plants in a plot reached one of the three different growth stages (Fehr et al 1971):

R2: Flowering stage characterized by the presence of a flower at the node immediately below the uppermost node with a completely unrolled leaf,

R3: Pod development stage, where the pod is 5 mm long at one of the uppermost nodes with a completely unrolled leaf,

R5: Seed development stage, where the beans are beginning to develop at one of the 4 uppermost nodes with a completely unrolled leaf.

Five levels of defoliation were selected (Figure 1):

0/6: The control, not defoliated,

1/6: Half of one leaflet for every fully developed leaf is removed,

2/6: One of the leaflets for every fully developed leaf is removed,

3/6: One and a half of the leaflets for every developed leaf are removed,

4/6: Two leaflets for every developed leaf are removed,

5/6: Two and a half leaflets for every developed leaf are removed.

The 3/6 level of defoliation was applied in the 1991/92 season only. In the 1991/92 season, treatments were carried out singly (one defoliation only) and sequentially. While in the previous season (90/91), the treatments were carried out sequentially only. Sequential defoliations were done by cutting, at the same level as previously indicated, the new leaves that emerge after the first defoliation. The R2 sequential treatments were done three times in total and the R3 sequential treatments were carried out twice in total. The R5 sequential treatments were defoliated once only, as very few new leaves emerge after this stage.

In the 1991/92 season, the leaf area was measured on one plant on 10% of the treatments, before and after defoliation treatments with a portable Leaf Area Meter, model LI-3000A (LI-COR 1988). Harvesting was done on the 22^{nd} to 25^{th} of April 1991 and on the 28^{th} of April 1992. All plots were hand harvested and processed. Records were collected for seed yield through yield components analysis. The number of pods, number of seeds, seed weight per plant and the weight of 100 seeds (at 8% moisture content) were measured for every experimental unit. The total yield in Kg/ha was derived from those measurements.

Irrigation was supplied regularly in order to maintain good soil moisture. However, due to the drought, in the 1991/92 year the irrigation schemes were focused on the soybean reproductive stages. In both years, herbicide (Dual®) was applied the day following planting and thereafter were hand weeded as necessary. In order to eliminate insect damage other than the simulated defoliation, the plots were sprayed with a mix of Karate®, Carbaryl® and Agral® or Thiodan® as natural insect pest populations appeared. Pesticides' chemical names are presented in Appendix I.

3.a.b. Greenhouse Trial

The greenhouse trial was conducted on the Crop Science Department's site of the University of Zimbabwe, Harare. Temperature and light were not controlled conditions. Minimum temperatures were $12.0^{o}C \pm 3.0$ and maximum temperatures were $36.0^{o}C \pm 4.0$. Two commercially available soybean cultivars (Roan, SCS1) were dipped in a mixture of Rhizobium, water and sugar and planted at 4 seeds per experimental unit (EU) on the 17th of July 1991 in humus and red clay (50:50). The plants were thinned to 1 plant per pot on the 21th of July 1991 and fertilized with ammonium nitrate (3 g/EU) every month.

The trial was laid out in a randomized complete block design with 3 replications in blocks with 48 treatments each (2.5 m X 1m). The plants were defoliated by cutting the whole soybean leaflet or half-leaflet along the midrib with scissors. The treatments were applied at the R2, R3 and R5 growth stages of the soybean plants (Fehr et al 1971). The levels of defoliations selected were 0/6, 1/6, 2/6, and 3/6 (Figure 1). They were either treated singly or sequentially. The plants were treated individually as they reached the growth stage required and the sequential defoliations were carried out as needed every two days.

The leaf area was measured on 10% of the treatments before and after defoliation with a portable Leaf-Area Meter, model LI-3000A (LI-COR 1988). All plots were hand harvested as they matured to the R8 growth stage (Fehr et al 1971) and hand processed. Records were collected for grain yield using yield component analysis. The number of pods, number of seeds, seed weight per plant and the weight of 100 seeds (at 8% moisture content) were measured for every experimental unit. The seed weight per plant was used as yield data. No herbicides or insecticides were applied.

3.a.c. Statistical Analysis

Data were analysed with standard analysis of variance for a Randomized Complete Block Design. Simple linear regression was used to estimate the relationship between percentage yield and percentage defoliation for each treatment. The percentage yield was derived from the yield data of the greenhouse experiment (g/plant) and of the field experiments (kg/ha).

The data fitted a linear model: $Y=a+bx$, where Y is the expected yield percentage, x is the percentage of simulated defoliation, a is the Y intercept representing the expected yield percentage where there is no defoliation, and b is the linear regression coefficient or the slope of the line indicating the percentage change in yield for each percentage change in defoliation.

Significant regression lines were compared individually with other significant regression lines, within the same experiment and with other experiments. Regressions or differences between regressions reported as significant have a probability of greater than F<0.05. The ANOVA and regression analysis were carried out with the M-Stat C statistical package (MSU 1990).

The predicted percentage of yield reductions were analysed by Student t-Test to determine the values that were significantly different from the non defoliated controls. Where the regression lines were not significant, the actual values were analysed with Student t-Tests as well. These percentage yield losses are presented in Tables 18 to 29, where the control (intercept) has been forced through 0 % losses. This is justified as maximum yield is expected to be obtained when there is no defoliation.

3.b. RESULTS

3.b.a. Greenhouse

The analysis of variance shows that the levels of defoliation as well as the timing of defoliation (single vs sequential) have a significant effect ($P<0.01$) on the yield (g/plant). The cultivars and the growth stages defoliated had no significant effect on the yield and none of the interactions between the factors were significant.

No significant relationship was obtained between the percentage of single defoliation and the yield loss of Roan and SCS1 at any of the growth stages (R2, R3, R5) (Tables 3-5). A significant negative linear relationship ($P<0.01$) was found between the sequential percentage defoliation and the yield of Roan cultivar at all growth stages (R2, R3, R5) (Tables 6-8). SCS1 cultivar did not respond to sequential defoliation at any of the soybean growth stages (R2, R3, R5) (Tables 6-8). The comparisons between the regressions did not show any significant differences in responses between the two cultivars.

The slope from the regression lines were consistently stronger, (with the exception of SCS1 at R5) for sequential defoliation compared to single defoliation. However the only significant difference between single and sequential defoliation was recorded for the Roan cultivar at the R2 growth stage ($P<0.05$), but this comparison was based on a non-significant regression line. No other treatments differed significantly in their responses to defoliation.

The standard deviations for the linear regressions were consistently high (s.d. > 0.318) and this is believed to be due to the high temperature fluctuation prevailing in the greenhouse. From the significant linear regression (i.e., Roan exposed to sequential defoliations), the minimum level of defoliation which significantly decreased the yield was 44% (level 3/6) from R3 and R5 sequential defoliation (Table 19-20).

3.b.b. Field Experiment 90/91

The analysis of variance shows that the different cultivars and the levels of defoliation employed have a significant effect ($P<0.01$) on the yield (kg/ha). The linear regressions lines determined for the 90-91 season were generally significant and the standard deviations were consistently low (s.d. < 0.216) (Table 9-11). Sequential defoliations initiated from R2, induced a significant negative linear relationship between the percentage yield and the percentage of defoliation for all cultivars (Duiker, Gazelle, Roan, SCS1) (Table 9). At the R3 growth stage, the sequential defoliations induced a highly significant negative linear relationship ($P<0.01$) between the two factors on Duiker and Gazelle cultivars. Roan cultivar showed a weaker but still significant relationship ($P<0.05$) and SCS1 a non significant relationship for this treatment (Table 10). The defoliations carried out at the R5 growth stage produced a highly significant relationship ($P<0.01$) between the percentage yield and the percentage defoliation for Gazelle and Roan cultivars. SCS1 showed a weaker but still significant relationship

(P<0.05) and Duiker a non significant relationship at the R5 growth stage defoliations (Table 11).

Comparisons were made between the significant linear regressions. Significant differences ($P < 0.05$) in reactions were noted at R2 with Duiker cultivar expressing a stronger reduction of yield than both Roan and SCS1. At R3, Roan was less susceptible to defoliation ($P<0.05$) than Gazelle and Duiker's response. At R5, Gazelle was more susceptible to defoliation ($P<0.05$) than Roan. No significant differences were noted between any growth stages within any of the four cultivars. The reductions in percentage yield at every experimental level of defoliations are presented on Tables 21-23. The minimum level of defoliation required to reduce the yield significantly under sequential defoliation is 58% (level 4/6) for Roan, Duiker and Gazelle. None of the defoliation levels applied to SCS1 significantly reduced its yield.

3.b.c. Field Experiment 91-92.

The analysis of variance shows that the cultivars, levels of defoliation, timing of defoliation, and the interactions between cultivars X timing, growth stages X timing and levels of defoliation X timing had highly significant effects ($P<0.01$) on the yield of soybean (kg/ha). The growth stages at which defoliations were carried out, did not have a significant effect on yield.

With defoliations carried out singly at the R2 growth stage, Duiker is the only cultivar to express a significant ($P<0.05$) negative linear relationship between percentage yield and percentage of defoliation (Table 12). When defoliated at R3 growth stage Duiker and Roan cultivars show a highly significant ($P<0.01$) negative linear relationship (Table 13). All cultivars exhibit this same relationship when defoliated at R5 (Table 14).

Sequential defoliation creates a stronger effect on yield than single defoliation. At R2 growth stage, Roan, Duiker ($P<0.01$), SCS1 and Gazelle ($P<0.05$) demonstrate negative linear relationship between percentage yield and percentage defoliation (Table 15). Roan, Duiker and SCS1 showed a highly significant ($P<0.01$) negative linear relationship at R3 and R5 (Tables 16-17), while Gazelle showed a significant relationship ($P<0.05$) at R3 but a non significant relationship at R5.

Comparisons did not prove to be significant for differences between significant regression lines of different cultivars. Consistently single defoliation has a weaker effect on the yield than sequential defoliation, but none of the significant regression lines were significantly different. The reductions in percentage yield at every experimental level of defoliation are presented on Tables 24 to 29.

Under single defoliation, the minimum defoliation level required to reduce Roan's and Duiker's yield was 44 % (level

3/6), 58% (level 4/6) for SCS1, and none of the levels was high enough to deplete Gazelle's yield. Under sequential defoliation Roan's yield was decreased when defoliation was greater than 44%. Duiker and SCS1 required more than 58% and Gazelle did still not respond significantly to any of the levels of defoliation applied.

3.c. DISCUSSION

The different cultivars used in this study did not respond the same way to defoliation except when grown in the greenhouse. In order to respond to the local space conditions, the greenhouse experiment was carried out on Roan and SCS1 cultivars only. In both experiments, there was no significant difference in the regression lines of these two cultivars. However it was noted that Roan consistently showed a steeper regression slope than SCS1, demonstrating a stronger response to defoliation.

Duiker consistently showed the strongest decrease in yield when defoliated singly. Roan had the strongest reduction in yield when defoliated sequentially except in the 90/91 season. In the first field experiment, Gazelle and Duiker showed the steepest slope and suffered higher yield reductions than in the 91/92 season. This is most probably due to the lower germination percentage of these two cultivars during the first year and consequent decreased compensation ability. Contrary to Fehr et al's (1981) findings, Roan, a determinate cultivar did not show significantly stronger yield reduction than the three indeterminate cultivars. It has been noted that Roan's leaf area is comparable to the other cultivars (Table 30), this is believed to allow it to sustain foliage damage as an indeterminate would. This increase in foliage might be due to the latitude at which Zimbabwe is situated. It has been shown that determinate cultivars grown in the southern United States achieve heights similar to those of indeterminates (Fehr et al 1981).

The growth stage at which the soybean plants were defoliated was not an important factor in relation to soybean response to damage. None of the experiments showed a significant effect of the growth stage and none of the comparisons carried out between the significant regression lines were significant. However under single defoliation, as the soybean plants are defoliated from the growth stage R2 to R5, an increase in the number of significant r^2 and in slope strength was noticed from the regression analysis (Tables 12-14). It would appear that with single defoliation, the younger the soybean plants are, the better they can compensate for defoliation and that the most susceptible growth stage would be during seed development (R5) (Caviness and Thomas 1980, Fehr et al 1981).

Generally the response of the percentage yield to increased defoliation is of a negative linear relationship. This agrees with many workers' findings (Hutchins et al 1988;

Nolting and Edwards 1989; Ostlie and Pedigo 1985). From these regression lines, the minimum level of single defoliation required to reduce yield significantly is 44% (level 3/6).

Although Caviness and Thomas (1980) mentioned that 50% defoliation was the minimum level reducing yield, it is comparable to the present study as they used a 3/6 defoliation level they did not measure the exact percentage. These results do not, however, agree with Taylor and Kunjeku's (1983) in which to significantly reduce yield as little as 20 % defoliation was needed at the pod development stage and 16 % at the seed development stage. Although the defoliation method was similar to the one used in this study, a different cultivar, Oribi, was utilized which could have shown more susceptibility to foliar damage than the four cultivars currently employed.

There are some discrepancies between the treatments which did not respond linearly to defoliation. Some of the very low levels of defoliation produced significant reduction in yield which were not replicated at higher levels of defoliation. The greenhouse experiment was not under a controlled environment. The maximum and minimum temperatures were exacerbated by the greenhouse conditions, which caused some of the treatments to abort, therefore rending the number of replicates insufficient, on Roan cultivar.

In field conditions, a drop in yield was found at R3 with SCS1 and R5 with Duiker in response to the 13% sequential defoliation in the 90/91 season. These results were not repeated in the second season. The main difference between the first and second season appears to be the amount of precipitation. Precipitation was discredited by Caviness and Thomas (1980) as a factor influencing the soybean pattern of response to defoliation. But Nolting and Edwards (1989) noted that other environmental factors which are associated with a wet or dry year could combine with precipitation, in order to change the pattern. It was noted that, since irrigation was supplied during the second and droughty season, the soybean plants, taking advantage of the increased heat units, were actually taller and healthier than in the first and more regular season.

These four cultivars were susceptible to foliage damage. SCS1 seems to be the most resistant cultivar by requiring very high levels of defoliation to significantly reduce the yield, as well as responding linearly less frequently than the other three cultivars. Roan and Duiker are the only two cultivars that showed a decreased yield with a 44% defoliation level. Duiker was the most susceptible cultivar to single defoliation.

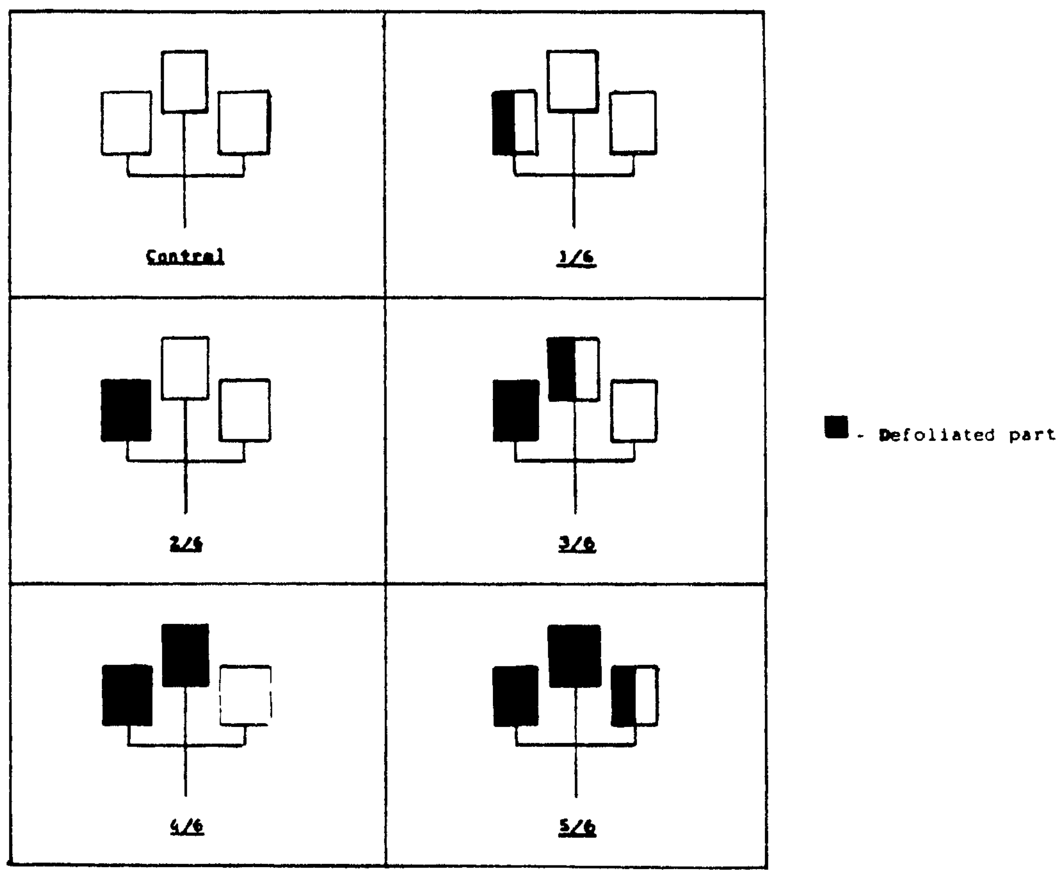

Figure 1: **Stylized depiction of the defoliation treatments of soybeans.**

Table 1 -Date of artificial defoliations with the growth stages* of soyabeans in field experiment 90-91.

Treatment	Date	Roan	SCS1	Duiker	Gazelle
R2a	1-4/02/91	R2	R2	R2	R2
R2b	12-13/02/91	R2	R2	R2	R2
R2c	15-18/03/91	R5	R5	R5-R6	R5
R3a	20-22/02/91	R3	R3	R3	R3
R3b	15-18/03/91	R5	R5	R5-R6	R5
R5	5/03/91	R5	R5	R5	R5

Table 2 -Date of artificial defoliations with the growth stages* of soyabeans in field experiment 91-92.

Treatment	Date	Roan	SCS1	Duiker	Gazelle
R2a	3-5/02/92	R2	R2	R2	R2
R2b	24/02/92	R2	R2	R2	R2
R2c	11-12/03/92	R5	R5	R5-R6	R5
R3a	24-25/02/92	R3	R3	R3	R3
R3b	11-12/03/92	R5	R5	R5-R6	R5
R5	5-6/03/92	R5	R5	R5	R5

* Growth Stages according to Fehr et al (1971).

a,b,c- correspond to the 1st, 2nd and 3rd defoliation treatments respectively.

Table 3. Parameter estimates for linear models fit to % defoliation - % yield data: R2[a]-single defoliation in greenhouse 1991.

CULTIVARS	r^2	a	b	s.d.
ROAN	0.002	109.576	-0.059	0.439
SCS1	0.119	100.847	-0.636	0.547

Table 4. Parameter estimates for linear models fit to % defoliation - % yield data: R3[a]-single defoliation in greenhouse 1991.

CULTIVARS	r^2	a	b	s.d.
ROAN	0.186	81.945	-0.714	0.472
SCS1	0.004	89.190	0.113	0.570

Table 5. Parameter estimates for linear models fit to % defoliation - % yield data: R5[a]-single defoliation in greenhouse 1991.

CULTIVARS	r^2	a	b	s.d.
ROAN	0.197	88.700	-0.732	0.467
SCS1	0.311	87.785	-0.879	0.413

a- growth stages according to Fehr et al (1971).
s.d- standard deviation
*,**- coefficient of regression significant at 0 05 and 0 01 level of sign respectively

Table 6. **Parameter estimates for linear models fit to % defoliation - % yield data: R2[a]-sequential defoliation in greenhouse 1991.**

CULTIVARS	r^2	a	b	s.d.
ROAN	0.402*	82.861	-1.008	0.410
SCS1	0.216	84.753	-0.740	0.445

Table 7. **Parameter estimates for linear models fit to % defoliation - % yield data: R3[a]-sequential defoliation in greenhouse 1991.**

CULTIVARS	r^2	a	b	s.d.
ROAN	0.656**	91.089	-1.319	0.318
SCS1	0.191	84.486	-0.784	0.510

Table 8. **Parameter estimates for linear models fit to % defoliation - % yield data: R5[a]-sequential defoliation in greenhouse 1991.**

CULTIVARS	r^2	a	b	s.d.
ROAN	0.453*	85.305	-1.150	0.399
SCS1	0.290	88.012	-0.785	0.388

a- growth stages according to Fehr et al (1971).
s.d- standard deviation.
*,**- coefficient of regression significant at 0.05 and 0.01 level of sign. respectively.

Table 9. Parameter estimates for linear models fit to % defoliation - % yield data: R2[a]-sequential defoliation in field 90-91.

CULTIVARS	r^2	a	b	s.d.
ROAN	0.692**	102.789	-0.544	0.101
SCS1	0.407**	108.190	-0.527	0.176
DUIKER	0.566**	92.553	-0.629	0.156
GAZELLE	0.691**	103.375	-0.742	0.138

Table 10. Parameter estimates for linear models fit to % defoliation - % yield data: R3[a]-sequential defoliation in field 90-91.

CULTIVARS	r^2	a	b	s.d.
ROAN	0.349*	104.389	-0.473	0.179
SCS1	0.076	86.044	-0.202	0.196
DUIKER	0.482**	95.733	-0.752	0.216
GAZELLE	0.585**	93.548	-0.622	0.145

Table 11. Parameter estimates for linear models fit to % defoliation - % yield data: R5[a]-sequential defoliation in field 90-91.

CULTIVARS	r^2	a	b	s.d.
ROAN	0.593**	111.086	-0.613	0.141
SCS1	0.360*	101.150	-0.380	0.141
DUIKER	0.172	84.137	-0.340	0.207
GAZELLE	0.490**	95.936	-0.611	0.173

a- growth stages according to Fehr *et al* (1971)
s d- standard deviation
*,**- coefficient of regression significant at 0.05 and 0 01 level of sign respectively.

Table 12. Parameter estimates for linear models fit to % defoliation - % yield data: R2[a]-single defoliation in field 91-92.

CULTIVARS	r^2	a	b	s.d.
ROAN	0.104	98.172	-0.180	0.132
SCS1	0.044	98.841	-0.144	0.169
DUIKER	0.233*	102.653	-0.329	0.149
GAZELLE	0.009	92.572	0.079	0.203

Table 13. Parameter estimates for linear models fit to % defoliation - % yield data: R3[a]-single defoliation in field 91-92.

CULTIVARS	r^2	a	b	s.d.
ROAN	0.643**	101.955	-0.493	0.092
SCS1	0.204	99.106	-0.248	0.122
DUIKER	0.570**	103.460	-0.591	0.129
GAZELLE	0.088	100.762	-0.219	0.176

Table 14. Parameter estimates for linear models fit to % defoliation - % yield data: R5[a]-single defoliation in field 91-92.

CULTIVARS	r^2	a	b	s.d.
ROAN	0.514**	98.356	-0.421	0.102
SCS1	0.452**	10[illegible].688	-0.508	0.140
DUIKER	0.666**	103.268	-0.555	0.098
GAZELLE	0.344**	105.783	-0.382	0.132

a- growth stages according to Fehr et al (1971).
s.d- standard deviation.
*,**- coefficient of regression significant at 0.05 and 0.01 level of sign. respectively.

Table 15. Parameter estimates for linear models fit to % defoliation - % yield data: R2[a]-sequential defoliations in field 91-92.

CULTIVARS	r^2	a	b	s.d.
ROAN	0.679**	104.227	-0.594	0.102
SCS1	0.226*	92.385	-0.338	0.157
DUIKER	0.527**	104.813	-0.525	0.124
GAZELLE	0.331*	96.879	-0.471	0.168

Table 16. Parameter estimates for linear models fit to % defoliation - % yield data: R3[a]-sequential defoliations in field 91-92.

CULTIVARS	r^2	a	b	s.d.
ROAN	0.742**	108.927	-0.795	0.123
SCS1	0.354**	98.266	-0.431	0.146
DUIKER	0.487**	107.236	-0.571	0.147
GAZELLE	0.341*	100.301	-0.525	0.182

Table 17. Parameter estimates for linear models fit to % defoliation - % yield data: R5[a]-sequential defoliations in field 91-92.

CULTIVARS	r^2	a	b	s.d.
ROAN	0.402**	103.412	-0.526	0.160
SCS1	0.504**	105.406	-0.537	0.133
DUIKER	0.487**	109.673	-0.507	0.130
GAZELLE	0.146	103.145	-0.354	0.215

a- growth stages according to Fehr et al (1971).
s.d- standard deviation.
*,**- coefficient of regression significant at 0.05 and 0.01 level of sign. respectively.

Table 18. **Predicted reduction in % yield: R2[a] in greenhouse 1991.**

Percent Defoliation	Roan simple	Roan sequential	SCS1 simple	SCS1 sequential
0	0	0	0	0
13	+ 0.7	15.8	8.1	43.1
28	7.9	34.1	13.0	43.1
44	8.6	53.6	29.8	38.2

Table 19. **Predicted reduction in % yield: R3[a] in greenhouse 1991.**

Percent Defoliation	Roan simple	Roan sequential	SCS1 simple	SCS1 sequential
0	0	0	0	0
13	53.2*	18.8	31.7	49.6
28	38.1	40.5	+ 5.7	34.1
44	42.4	63.7*	7.3	45.5

Table 20. **Predicted reduction in % yield: R5[a] in greenhouse 1991.**

Percent Defoliation	Roan simple	Roan sequential	SCS1 simple	SCS1 sequential
0	0	0	0	0
13	29.5	17.5	43.9	36.6
28	46.8*	37.7	30.9	39.0
44	31.7	59.3*	48.8	39.0

a- Growth stages according to Fehr et al (1971).
*,**- Trt. sign. different from the control at 0.05 and 0.01 level of sign respectively by the Student t-test.

Table 21. Predicted reduction in % yield: R2[a]-sequential defoliation in field 90-91.

Percent Defoliation	Roan	SCS1	Duiker	Gazelle
0	0	0	0	0
13	6.9	6.4	8.8	9.4
28	14.8	13.8	19.1	20.1
58	30.6**	28.3	39.4	41.7**
66	34.9**	32.2	44.9	47.4**

Table 22. Predicted reduction in % yield: R3[a]-sequential defoliation in field 90-91.

Percent Defoliation	Roan	SCS1	Duiker	Gazelle
0	0	0	0	0
13	5.9	41.4*	10.1	8.6
28	12.7	12.0	21.9	18.6
58	26.3	12.4	45.6*	38.6*
66	29.9	37.3*	51.8*	43.9**

Table 23. Predicted reduction in % yield: R5[a]-sequential defoliation in field 90-91.

Percent Defoliation	Roan	SCS1	Duiker	Gazelle
0	0	0	0	0
13	7.2	4.9	37.8*	8.2
28	15.5	10.6	29.8	17.8
58	32.0*	21.8	30.0	36.9*
66	36.5**	24.9	38.0*	42.0*

a- Growth stages according to Fehr et al (1971)
*,**- Trt sign. different from the control at 0.05 and 0.01 level of sign. respectively by the Student t-test.

Table 24. **Predicted reduction in % yield: R2[a]-single defoliation in field 91-92.**

Percent Defoliation	Roan	SCS1	Duiker	Gazelle
0	0	0	0	0
13	3.4	7.3	4.2	16.8
28	8.9	4.8	9.0	14.6
44	10.4	1.8	14.1	+ 8.0
58	21.2*	8.3	18.6	+16.0
66	4.8	14.9	21.1	+20.9*

Table 25. **Predicted reduction in % yield: R3[a]-single defoliation in field 91-92.**

Percent Defoliation	Roan	SCS1	Duiker	Gazelle
0	0	0	0	0
13	6.4	7.9	7.4	3.5
28	13.5	6.4	16.4	+ 0.7
44	21.3*	10.3	25.1*	14.4
58	28.0**	8.4	33.1**	10.1
66	32.0**	24.2	37.7**	13.9

Table 26. **Predicted reduction in % yield: R5[a]-single defoliation in field 91-92.**

Percent Defoliation	Roan	SCS1	Duiker	Gazelle
0	0	0	0	0
13	5.6	6.4	7.0	4.7
28	12.0	13.7	15.1	10.1
44	18.9	21.6	23.7*	15.9
58	24.9*	28.4*	31.2**	21.0
66	28.3**	32.3*	35.5**	23.8

a- Growth stages according to Fehr et al (1971).
*,**- Trt. sign. different from the control at 0.05 and 0.01 level of sign. respectively by the Student t-test.

Table 27. **Predicted reduction in % yield: R2[a]-sequential defoliation in field 91-92.**

Percent Defoliation	Roan	SCS1	Duiker	Gazelle
0	0	0	0	0
13	7.4	4.8	6.5	6.3
28	15.9	10.3	14.0	13.6
44	25.0**	16.1	22.0	21.4
58	33.0**	21.2	29.0*	28.2
66	37.6**	24.1	33.0**	32.1

Table 28. **Predicted reduction in % yield: R3[a]-sequential defoliation in field 91-92.**

Percent Defoliation	Roan	SCS1	Duiker	Gazelle
0	0	0	0	0
13	9.5	5.7	6.9	6.8
28	20.4	12.3	14.9	14.7
44	32.1**	19.3	23.3	23.0
58	42.3**	25.4	30.9*	30.3
66	48.1**	29.0	35.1*	34.5

Table 29. **Predicted reduction in % yield: R5-sequential defoliation in field 91-92.**

Percent Defoliation	Roan	SCS1	Duiker	Gazelle
0	0	0	0	0
13	6.6	6.6	6.0	10.9
28	14.2	14.2	12.9	+ 2.4
44	22.3	22.4	20.3	0.5
58	29.5	29.5*	26.8*	5.1
66	33.6 *	33.6*	30.5*	41.0*

a- Growth stages according to Fehr *et al* (1971).
*,**- Trt. sign. different f om the control at 0.05 and 0.01 level of sign. respectively by the Student t-test

Table 30 - **Leaf area (cm^2) of 4 soybean cultivars at 3 growth stages[a].**

Cultivar	R2	R3	R5
Roan	2017	3602	3006
SCS1	1986	3364	2371
Duiker	1864	2635	2814
Gazelle	2340	2939	3591

a. Growth stages according to Fehr et al (1971).

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4. CONSUMPTION OF SOYBEAN FOLIAGE AND DEVELOPMENT TIME

The principal objective of this study is to determine the leaf-consumption potential of the most common semilooper in Zimbabwe, Trichoplusia orichalcea (F.) when feeding on four soybean cultivars, Duiker, Gazelle, Roan and Gazelle.

4.a. MATERIALS AND METHODS

Moths of Trichoplusia orichalcea (F.), Chrysodeixis acuta (Wlk.) and C. chalcites (Esp.) were caught nightly by light trap (mercury bulb) on the Crop Science Department of the University of Zimbabwe's site in Harare (17° 475'S, 31° 03'E). The moths were identified at the species level and sexed. Monthly catches are presented in Figure 2 for the month of August 1990 to the month of April 1991 (Lapointe 1991). The second season's records are not presented since the year 91-92 was very dry and the semiloopers did not show an increase in population. The species proportions are presented in Figure 3 (Lapointe 1991). T. orichalcea was the most common semilooper species encountered, therefore was the one chosen for the leaf consumption experiment.

Females of T. orichalcea were placed in 1 lt. glass jars, lined with paper towel for egg laying. Moth food sources consisted of sugar and water solution on cotton wool, placed in a small plastic Petri dish of 3.5 cm diameter. Eggs were collected at the black head stage for the laboratory consumption experiment.

In order to simulate the field conditions as much as possible, the plant material was selected from field grown soybean cultivars Duiker, Gazelle, Roan and SCS1. The cultivars were planted on the 9th of December 1991 on the Crop Science Department plot of the University of Zimbabwe and exposed to regular agronomic practices. Soybean leaves were selected at random; except that only fully developed leaflets were picked, from all levels of the canopy (Beach and Todd 1988). The leaves were immediately taken to the laboratory, where they were washed in tap water, then dipped for 10 minutes in 0.25 % sodium hypochlorite, rinsed 4 times in water and dried between sheets of paper towel. This was believed to surface sterilize the leaves (Tuite 1969) and eliminate predators.

Individual leaves were then placed in plastic Petri dishes of 9 cm of diameter, lined with one layer of sterilized vermiculite and filter paper (Figure 4) (Taylor and Kunjeku 1983). If needed, water was added twice daily to the vermiculite and to the cotton wool surrounding the petiole. The dishes were stacked in a non-functioning fume hood. To reduce condensation, the plastic Petri dishes were pierced ten times on the top part of the plates with a 5 ml injection needle, Taylor and Kunjeku (1983) used a gauze window but the method described here was successful and easier to set up. Two eggs at the black head stage were placed in each Petri dish. On the second day most of the eggs had hatched and on the third day the plates were screened and left with only one larva per plate.

Treatments consisted of 25 replications per soybean cultivar making a total of 100 observations. The four cultivars were blocked by stacks of dishes and after daily measurements, stacked at random within their block. The leaf-area of all leaves was measured with a leaf area meter, model LI-3000A (LI-COR 1988) before and after insect damage (Hammond et al 1979). The first measurement was taken 3 days after eggs hatched, the second measurement 5 days after egg hatching and the subsequent ones on a daily basis.

From the 7th day, depending on their size, two leaves were placed per Petri dish so that the larvae would not lack food or change their consumption rate by feeding on veins or petioles. Larval mortality was monitored daily. The cumulative larval and pupal mortality is presented in Table 32. After pupation, the pupae were transferred to individual 250 ml glass jars and development to adult stage was observed on a daily basis. The number and the sex of the emerging moths was established and is presented in Table 33.

The laboratory conditions were not under controlled environment, but determined by the natural conditions. The photoperiod was 12.30:11.30 (L:D), the minimum temperature was 25.0 ± 1.0 °C and the maximum temperature 30.0 ± 2.0 °C. Significance of differences between means was tested by analysis of variance (P > 0.05). When found significant the means were then tested by the Student t-test. The mean daily consumption of T. orichalcea larvae and their standard errors on the four soybean cultivars are presented in Table 31.

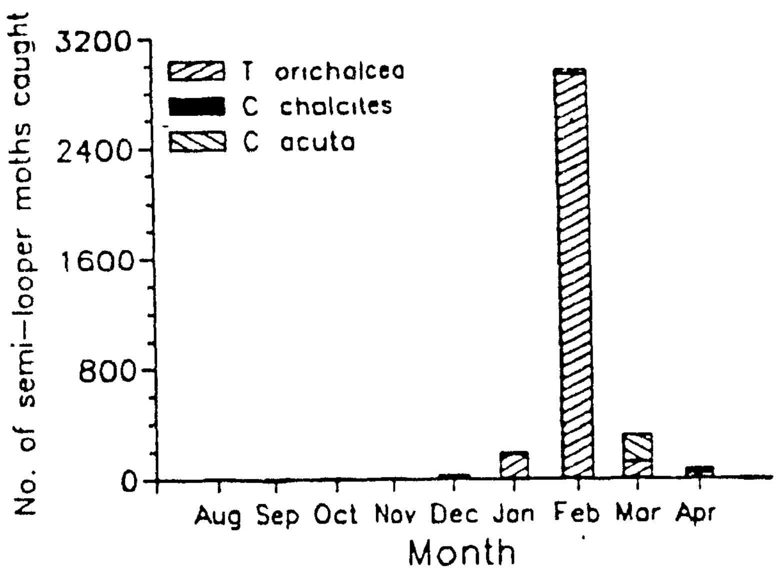
4.b. RESULTS AND DISCUSSION

Larvae of T. orichalcea consumed the same amount of foliage of any of the four cultivars studied. However a significantly lower amount of SCS1 foliage was consumed on the 7^{th} day as well as Duiker foliage on the 9^{th} day of the experiment. T. orichalcea larvae ate an average of 120.849 ± 2.34 cm^2 per individual. Taylor and Kunjeku (1983) found that T. orichalcea larvae consumed 161.02 cm^2 of soybean foliage; when fed on greenhouse grown plants. Boldt et al (1975) found that larvae of Trichoplusia ni (H.) ate 21.6 % less foliage when fed field compared to greenhouse grown soybean leaves. Hammond et al (1979) found that Plathypena scabra (F.) feeding on field grown soybean consumed only 46.1 % as much foliage as when fed greenhouse grown soybean. This would account for most of the differences in results between Taylor and Kunjeku (1983) and this study. Other factors which could be involved in the differences are the ambient temperature as well as the cultivars on which T. orichalcea larvae were fed.

The development period of the larvae did not vary significantly regardless of the four cultivars on which they were reared. The larvae ate most on the 9^{th} day, eating over 40 % of their total leaf consumption. Over 90 % of the foliage consumption was achieved during the last three days of the larval stage, so less than 10 % of the defoliation is done on the first seven days after hatching. This pattern of feeding, by which the larvae consume most of the foliage on the last days of larval development is consistent with other Noctuidae (Boldt et al 1975).

The larvae reached the prepupal stage in 11 days (only 1/100 larvae took 12 days) as seen by cessation of feeding and changes in the larvae shape. The adult stage was reached in 19 days. The development period of the entire larval stage was shorter than Taylor and Kunjeku's (1983) by 7 days. Boldt et al's study (1975) showed that *T. ni* larvae which are fed on field grown soybean plants take 2 days less to reach the pre-pupal stage than when they are fed on greenhouse grown plants. In Taylor and Kunjeku's study (1983), the temperature was kept at 25 °C , this is believed to be responsible for the longer larval development period. Other Noctuidae have shown this differential development time as related to temperature (Boldt et al 1975; Hammond et al 1979; Trichilo and Mack 1989).

20 % of the larvae feeding on Roan and Gazelle and 24 % of the larvae feeding on SCS1 and Duiker died before pupation, while 29 % of the larvae died either in prepupation or during pupation. Therefore 51 % of *T. orichalcea* larvae did not survive to the adult stage. Observations on the adult sexes gave a ratio of 6:1 females to males emerging from pupae.



<u>Figure 2:</u> Number of semilooper moths caught monthly by light trap at the Crop Science Department of the University of Zimbabwe, Harare from August 1990 to April 1991.

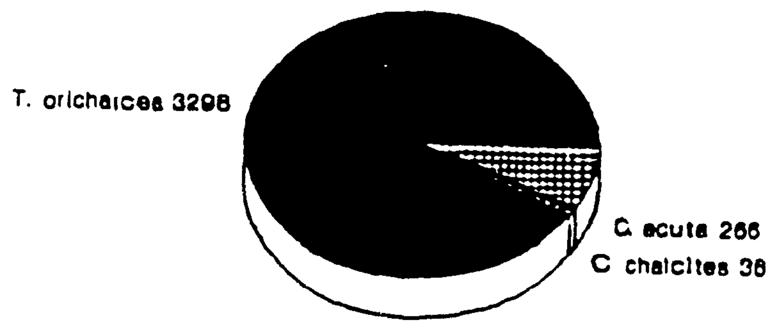


Figure 3: Species composition of the semilooper moths caught by light trap at the Crop Science Department of the University of Zimbabwe, Harare from August 1990 to April 1991.

Figure 4: Petri dish used for T. orichalcea leaf consumption experiment.

Table 31. Consumption of leaves (cm^2)[a] of the 4 soybean cultivars and development time of *T. orichalcea* larvae.

Days[b]	Roan	SCS1	Duiker	Gazelle	Average
3	-0.82 ± 0.80	-1.33 ± 0.82	-1.87 ± 0 82	1.01 ± 0 80	-0. 73± 0.41
5	-0.98 ± 1.18	1.49 ± 1.21	1 12 ± 1 21	-2.37 ± 1.18	-0 22 ± 0.61
6	5.71 ± 1.25	6 31 ± 1.29	5 05 ± 1 29	6.19 ± 1.25	5.82 ± 0.62
7	6.69 ± 1 41	-1 25 ± 1 45	7 75 ± 1 45	6.63 ± 1.41	5.00 ± 0.81
8	27.20 ± 2.53	30.57 ± 2.60	34.03 ± 2.60	30.92 ± 2.53	30.64 ± 1.29
9	59.58 ± 3.13	58.59 ± 3 21	43 22 ± 3 21	55.59 ± 3.13	54.35 ± 1.72
10	28 14 ± 2 91	22.14 ± 2 98	27 11 ± 2 98	27 09 ± 2.91	25.90 ± 1.47
11	0 00 ± 0 18	0.38 ± 0.19	0 0 ± 0.19	0 00 ± 0.18	0.09 ± 0.09
Total	125.53 ± 4 62	117 0 ± 4.74	116.40 ± 4.74	124.06 ± 4.62	120.85 ± 2.34

a- Means and SE for leaf consumption of 20 larvaes for Roan and Gazelle, and 19 larvaes for SCS1 and Duiker cultivars

b- Number of days after hatching of *T orichalcea* eggs

Table 32. Mortality of *T. orichalcea* when fed on 4 different soybean cultivars.[a]

Insect Stage	Roan	SCS1	Duiker	Gazelle	Total
Larvae	5	6	6	5	22
Pupae	8	8	9	4	29

a- Data taken from 25 replications per cultivar.

Table 33. Sex ratio of *T. orichalcea* when fed on 4 different soybean cultivars.[a]

Cultivar	Female	Male
Roan	9	3
SCS1	10	1
Duiker	9	1
Gazelle	14	2
Total	42	7

a- Data taken from the moths successfully emerging from pupal cases.

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5. ECONOMIC INJURY LEVELS AND ECONOMIC THRESHOLDS

5.a. INTRODUCTION

Soybean [illegible] pers are encountered in increasing numbers in Zimbabwe [illegible] ruary to March (Figure 2). This period corresponds to the [illegible] vegetative and the reproductive growth stages of soybean. It has been established that defoliation before the reproduc[illegible] growth stages has produced little effect on the se[illegible] yield (Dent 1991, Fehr et al 1981, Shibles et al [illegible] and Lee 1988) and that, for defoliation, [illegible] cal growth stage is the seed development stage (P5) [illegible]ehr et al 1981). The soybean producers in Zimbabwe do not apply chemical insecticides very frequently on soybean crop, instead they prefer to wait for a complex of nuclear polyhedrosis viruses to invade their fields (Pers. com., D. Taylor, COPA). It may be, however, economical to apply chemical pesticides once a certain caterpillar population is reached. Three chemical insecticides are recommended for the control of soybean semiloopers in Zimbabwe: endosulfan, fenvalerate and monocrotophos. (Hutchison 1988, Pers. com., D. Taylor, COPA).

The economic threshold (ET) and economic injury levels (EIL) concepts were first introduced by Stern et al (1959). The EIL is defined as the lowest population density that will cause economic damage and the ET as the density at which control measures should be initiated to prevent an increasing pest population from reaching the EIL. The economic damage or gain threshold (Stone and Pedigo 1972) is defined as the amount of injury required to cause enough monetary loss to offset the cost of artificial measures (Stern et al 1959, 1966).

By establishing the relationship between soybean yield reduction, foliar damage in Chapter 3) and pest density (Chapter 4), it has been possible to calculate the EIL and ET for the most frequently encountered soybean semilooper, Trichoplusia orichalcea (F.) (Figure 3).

5.b. ECONOMIC DAMAGE

Economic damage (Kg/ha) was calculated from Stone and Pedigo's formula (Stone and Pedigo 1972):

$$\text{Economic Damage (Kg/ha)} = \frac{\text{cost of chemical control (\$/ha)}}{\text{market value of soybean (\$/Kg)}}$$

The economic damage (ED) levels presented in Table 35 were calculated for three insecticides applied either with a knapsack or from aerial spray. The cost of knapsack spraying is Z.$6.38/ha and aerial spraying costs on average Z.$45/ha. ED are presented both as Kg/ha and as percent yield loss in order to estimate the number of caterpillars necessary to cause loss equal to the gain threshold. The percent yield loss was based on the average Zimbabwean soybean production of 2000 Kg/ha. The costs of single application rates are presented in table 34 (Pers. com., D. Taylor, COPA). Market value of soybean for 1992 was established at Z.$950 for one ton of B grade seeds. (Pers. com., D. Taylor, COPA).

5.c. ECONOMIC INJURY LEVELS AND ECONOMIC THRESHOLDS

Economic injury levels were calculated only from significant regression equations (Chapter 3). The other equations are not considered as they do not demonstrate a significant relationship between defoliation and yield for those treatments. Only the regression equations derived from the single defoliations are used. By observing the semilooper population, a few days before specific soybean growth stages, the producer should be able to decide whether the insect population level is sufficient to require insecticide applications or not.

The steps necessary to calculate the EIL were obtained from Stone and Pedigo (1972). Having already determined the percent yield loss, it was necessary to transfer these data into percent yield because when there is no defoliation the yield is 100%. The addition of this step was necessary due to the nature of our regressions (Chapter 3). The regressions were based on percent yield not on percent yield reduction. Therefore at 0% defoliation, the yield was 100% and any defoliation brought an equivalent yield decrease.

The determination of the percent defoliation (x) necessary to cause that % yield decrease was taken from the regression equations of % yield on % defoliation, where $x=(Y-a)/b$. Y represents the percent yield, a is the Y intercept and b the slope of the regression lines. The regression lines and equations are presented in Figures 5 to 8. The percent defoliation necessary is then converted into absolute defoliation by multiplying it by the total foliage and then divided by 100%. The total foliage was measured with leaf-area meter, model LI-3000A, as a control for every growth stages defoliated in the 1991-92 field experiment described in Chapter 3, they are tabulated in Table 34.

The plant EIL equals the absolute defoliation necessary (cm^2) divided by the foliage consumption of 120.85 cm^2 per larva. The foliage consumption was determined in the laboratory experiment described in Chapter 4. The EIL is the plant EIL multiplied by the number of plants per meter of row. At a soybean population of 300 000 plants/ha, with a row spacing of 0.75m, the number of plants per meter of row is 22.5.

The EILs are presented in Table 37 and in Figures 9 to 12. The EILs varied with the cultivars and growth stages monitored but even more with the insecticides and application methods used. The difference of EILs between the insecticides and application methods used is related simply to the high differences in costs between the treatments. On the assumption that a period of 24 hours is necessary to implement control measures, the economic thresholds would be at the same levels as the EILs but one day before the reproductive growth stage being monitored.

These EILs are much higher than those of Taylor and Kunjeku (1983), for Oribi cultivar, where the conclusion reached was that it was economical to apply pesticides as soon as the caterpillars are noticed in the field. Their gain threshold was similar to the gain threshold calculated here for endosulfan with aerial application but the average yield utilized was the experimental yield of 3930 Kg/ha instead of the national average yield. The laboratory foliage consumption of T. orichalcea was determined from greenhouse-grown soybean leaves which increased the leaf consumption per individuals of 40 cm^2 (33% more) and the total leaf area in field was lower than in the present experiment. Cameron et al (1986) who had worked with C. eriosoma, a sister species of C. chalcites, had determined an EIL of 22 larvae/m of row and they noted that thresholds vary in a complex manner with variations in economic and agronomic parameters.

The EILs are determined using caterpillar catches with the ground cloth techniques (Kogan and Pitre 1980) . The sampling procedures are described in the Oilseeds Handbook (Hutchison 1988). The technique consists of laying a white cloth (0.75m wide * 1.0m long) between two rows of soybeans and beating down the plants of one row on the cloth, in a vertical motion. Then the larvae can be counted either on the site or placed in identified jars and collected for later identification and counts of the caterpillars. If the samples are to be identified later, then a plastic sheet would be more appropriate than a canvas since the insects would slide more easily in the jar (Shepard and Carner 1976).

5.d. CONCLUSION

Although the EILs are related to relatively low defoliation and consequently a low insect population, most of the levels, with the exception of Roan at R5 growth stage, show an insect population that would rarely be encountered in the field (Taylor and Kunjeku 1983). This was acknowledged by Cameron et al (1986) who defined a C. eriosoma infestation of 20 larvae/m of row to be medium, 50/m of row to be high and 70/m of row to be very high. Singh et al (1987) found C. acuta reached a maximum of 14.7 larvae/10 plants and Hill et al (1987) found a maximum of 20 T. orichalcea and C. eriosoma larvae/m of row.

A high larval mortality would increase the EILs as supported by the data obtained in the leaf area consumption experiment in laboratory (Chapter 4). But because of the lack of information on the field population dynamics of the semilooper complex, it is not possible to apply these results to the present study. The laboratory experiment resulted in a 22% mortality rate of the larvae, and the field experience also suggested a high degree of predation and diseases under natural conditions.

In the laboratory experiment, during the 11 days duration of larval stadia, the last 3 days resulted in 90% of the defoliation. Therefore, we can take advantage of the period where the larvae consume little amount of foliage to record diseases, parasitism and predation when monitoring small larvae.

Monitoring at weekly intervals, should be started before the reproductive growth stages of soybean. When the number of caterpillars approaches the ETs, monitoring should be carried out more frequently and special attention should be given to the semiloopers size and health state. Chemical control should be applied only when ETs are reached and when natural mortality factors are not likely to prevent semilooper populations from reaching the EILs.

The NPV complex subsisting in Zimbabwe gives a great opportunity to define the EILs and ETs with a biological control agent. The time difference between the EIL and the ET would be wider because the action of biological control agents is slower than that of chemical insecticides. These ET values have been determined in Natural Region II a of Zimbabwe (Vincent and Thomas 1961) and extrapolation to other regions should be done with caution.

Updating EILs for new insecticide and application costs as well as market value of soybean might need to be carried out periodically. Once the economic damages are calculated and the percent yield determined, the EIls and ETs could be recalculated directly from Figures 12 to 18 unless environmental changes are sufficient to induce a different soybean susceptibility to defoliation.

Table 34. **Semilooper control cost with different insecticides**[a].

Insecticide	Quantity ml/ha	Knapsack Z.$/ha	Aerial Z.$/ha
Endosulfan	500	32.05	70.67
Fenvalerate	175	37.53	76.15
Monocrotophos	500	37.50	76.12

a. Control cost includes the insecticide price and application cost.

Table 35. **Economic damage level.**

Insecticide + application method	ED in Kg/ha	ED in % yield
Endosulfan Knapsack	33.74	1.69
Endosulfan Aerial	74.39	3.72
Fenvalerate Knapsack	39.50	1.98
Fenvalerate Aerial	83.32	4.17
Monocrotophos Knapsack	39.47	1.97
Monocrotophos Aerial	80.13	4.01

Table 36. **Total foliage area of soybean at 3 growth stages.**

Soybean Growth Stage[a]	Leaf-Area cm^2 [b]
R2	2033.74 ± 107.75
R3	3256.70 ± 248.56
R5	2987.44 ± 139.14

a. Growth stages according to Fehr et al 1971.
b. Means and SE for leaf-area (cm^2) based on 28, 15 and 10 observations at R2, R3 and R5 growth stages respectively.

Table 37. Economic injury levels in numbers of semilooper caterpillars per meter of row.

Soybean Growth Stage* + Cultivar	Insecticide 1a	Insecticide 1b	Insecticide 2a	Insecticide 2b	Insecticide 3a	Insecticide 3b
R2 Duiker	50	73	53	79	53	77
R3 Roan	45	70	48	75	48	73
R3 Duiker	53	73	56	78	56	77
R5 Roan	1	27	4	33	4	31
R5 SCS1	59	81	62	86	62	84
R5 Duiker	50	70	53	75	53	73
R5 Gazelle	109	138	113	145	113	143

*. growth stages according to Fehr et al (1971).

1a. endosulfan knapsack
1b. endosulfan aerial
2a. fenvalerate knapsack
2b. fenvalerate aerial
3a. monocrotophos knapsack
3b. monocrotophos aerial

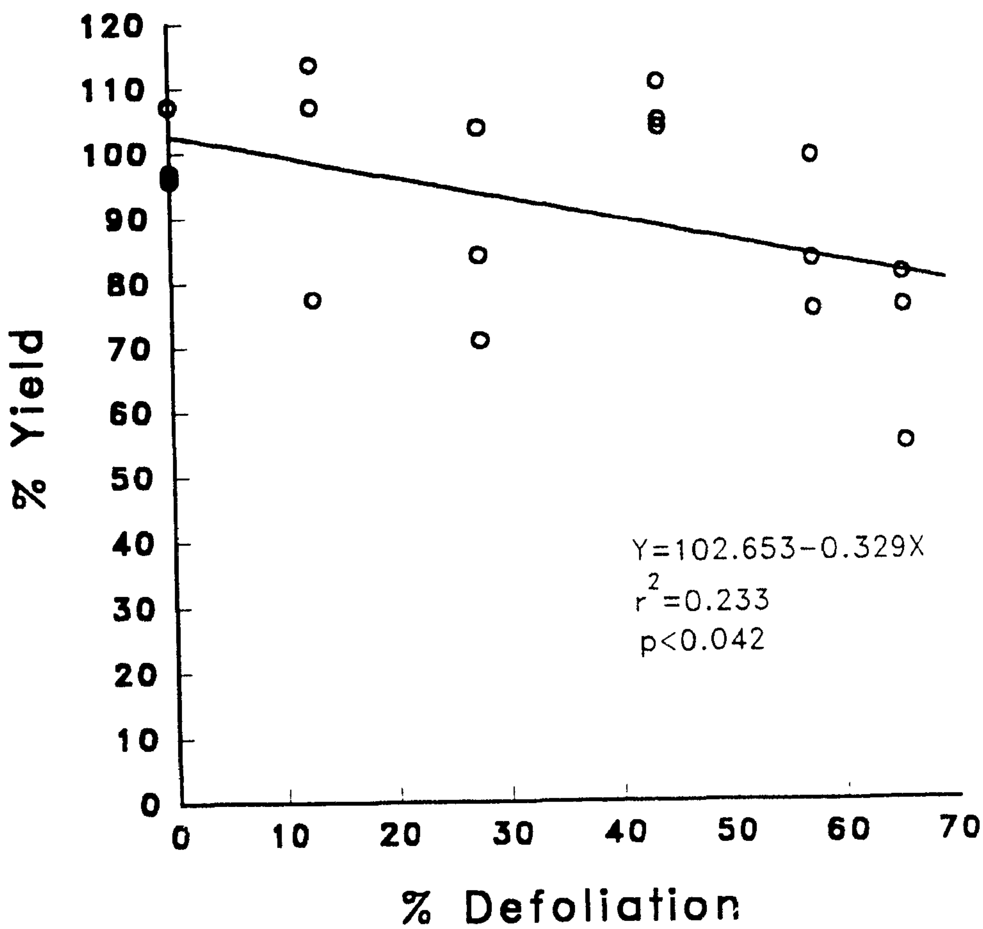


Figure 5: Relation between percent artificial defoliation (X) at R2 growth stage on Duiker soybean cultivar and percent yield (Y). Parameter estimates obtained from Table 12.

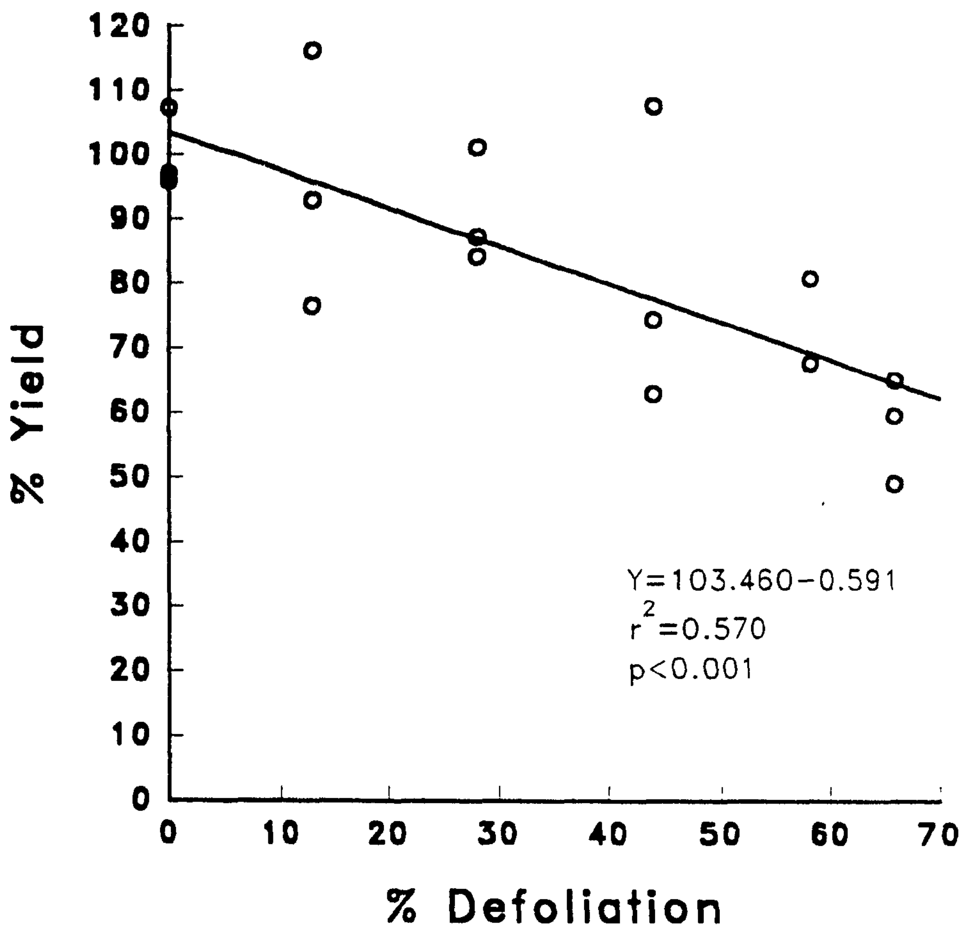


Figure 6: **Relation between percent artificial defoliation (X) at R3 growth stage on Duiker soybean cultivar, and percent yield (Y). Parameter estimates obtained from Table 13.**

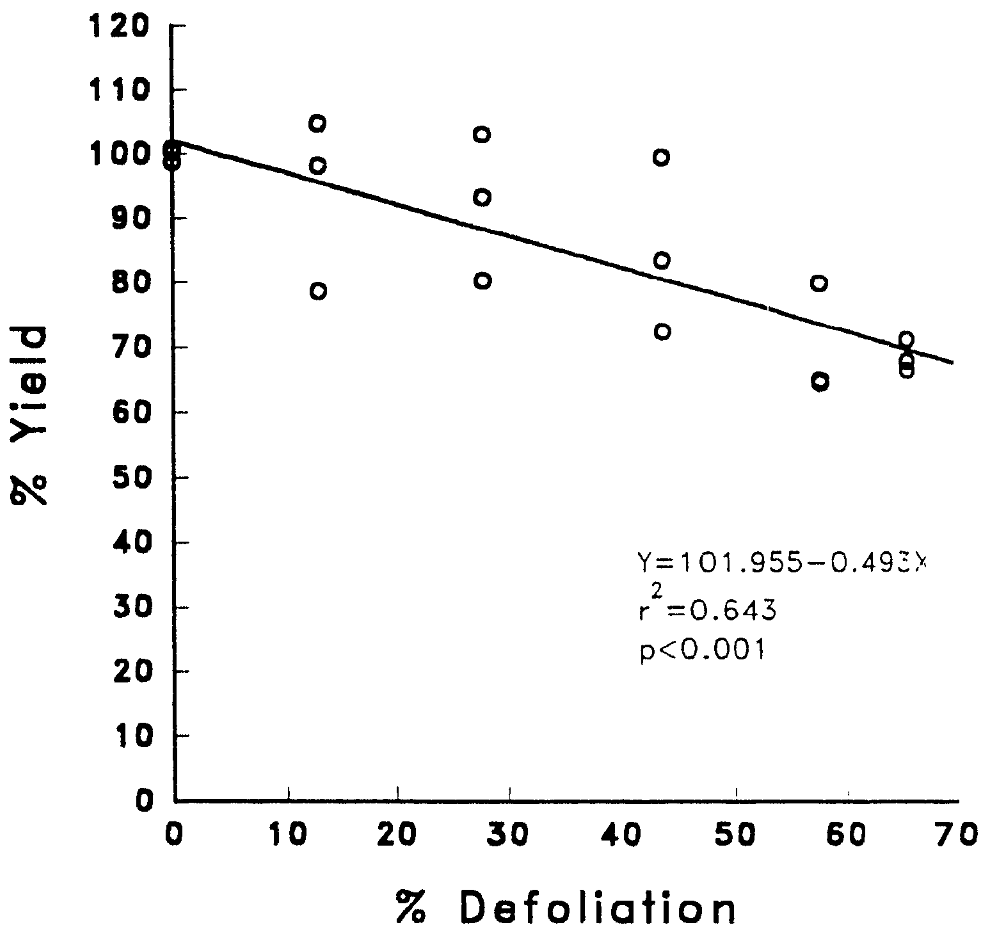


Figure 7: Relation between percent artificial defoliation (X) at R3 growth stage on Roan soybean cultivar, and percent yield (Y). Parameter estimates obtained from Table 13.

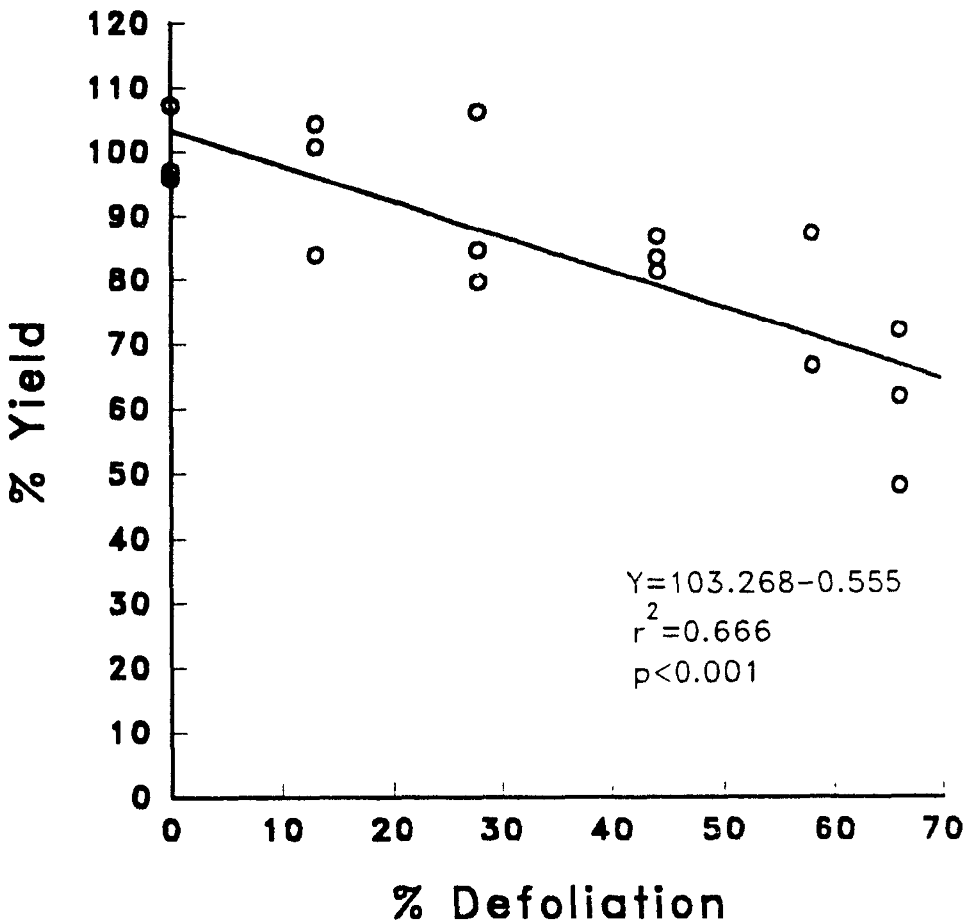
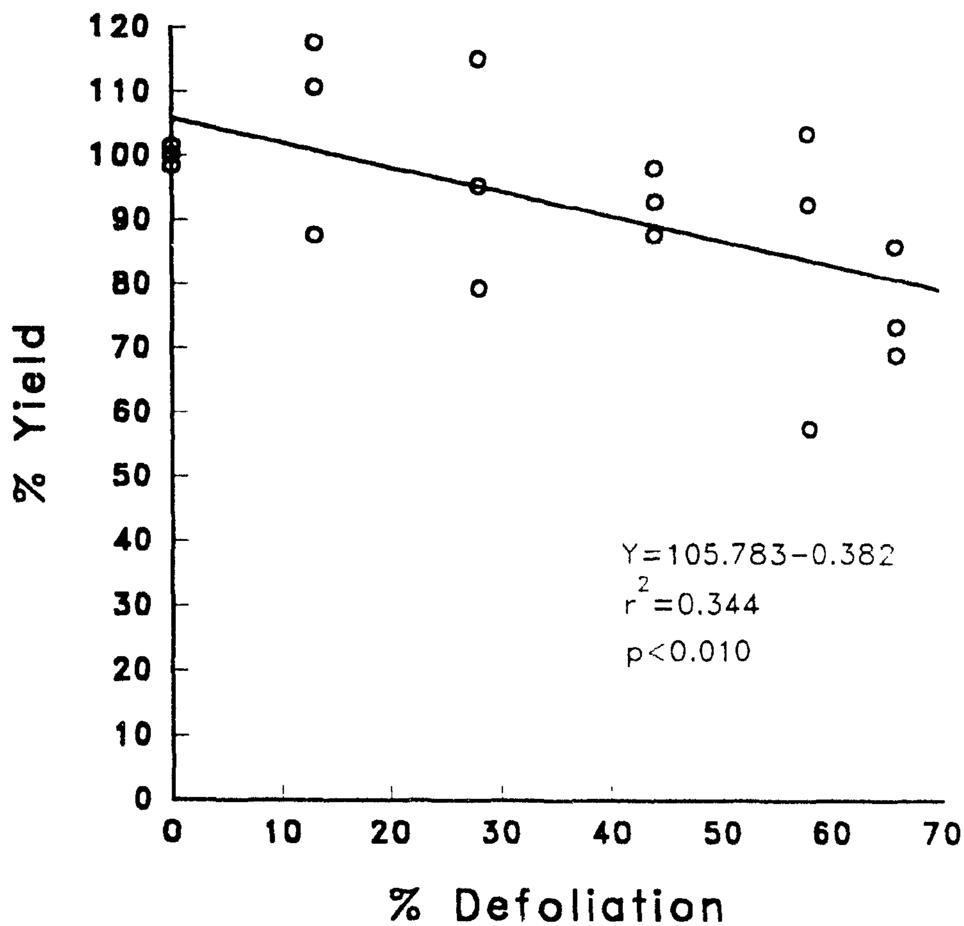


Figure 8: **Relation between percent artificial defoliation (X) at R5 growth stage on Duiker soybean cultivar, and percent yield (Y). Parameter estimates obtained from Table 14.**



<u>Figure 9:</u> Relation between percent artificial defoliation (X) at R5 growth stage on Gazelle soybean cultivar, and percent yield (Y). Parameter estimates obtained from Table 14.

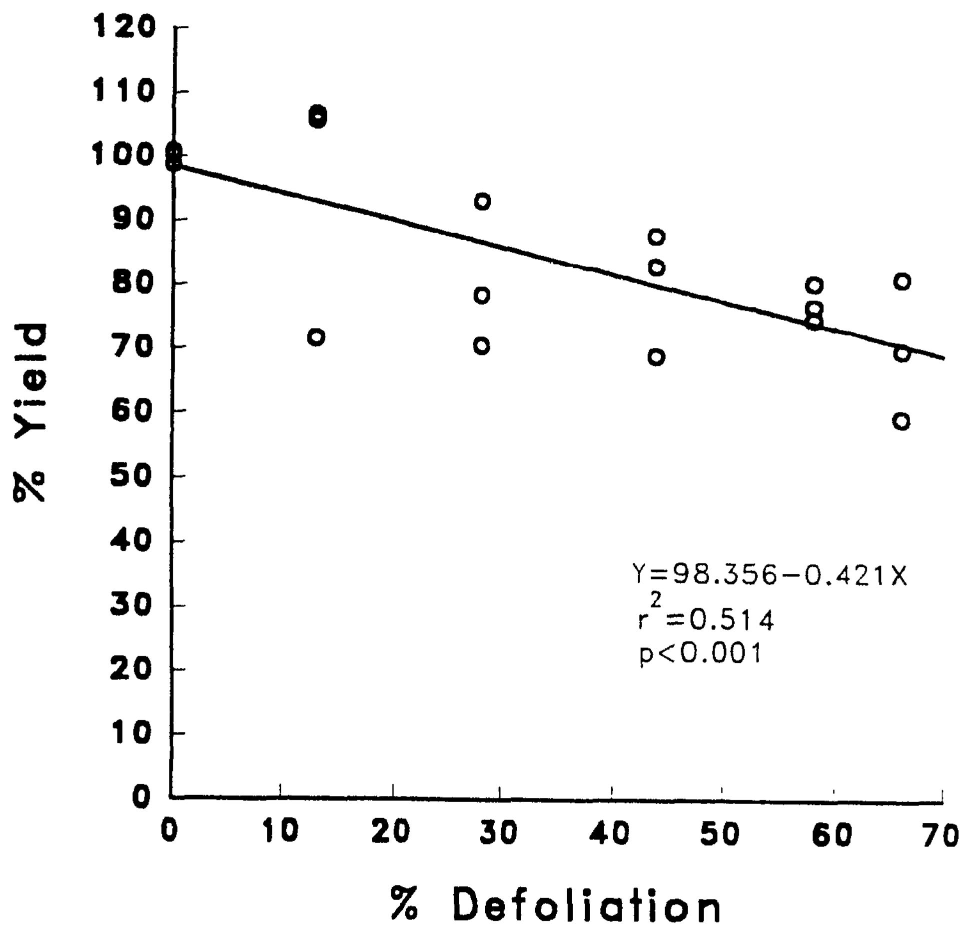
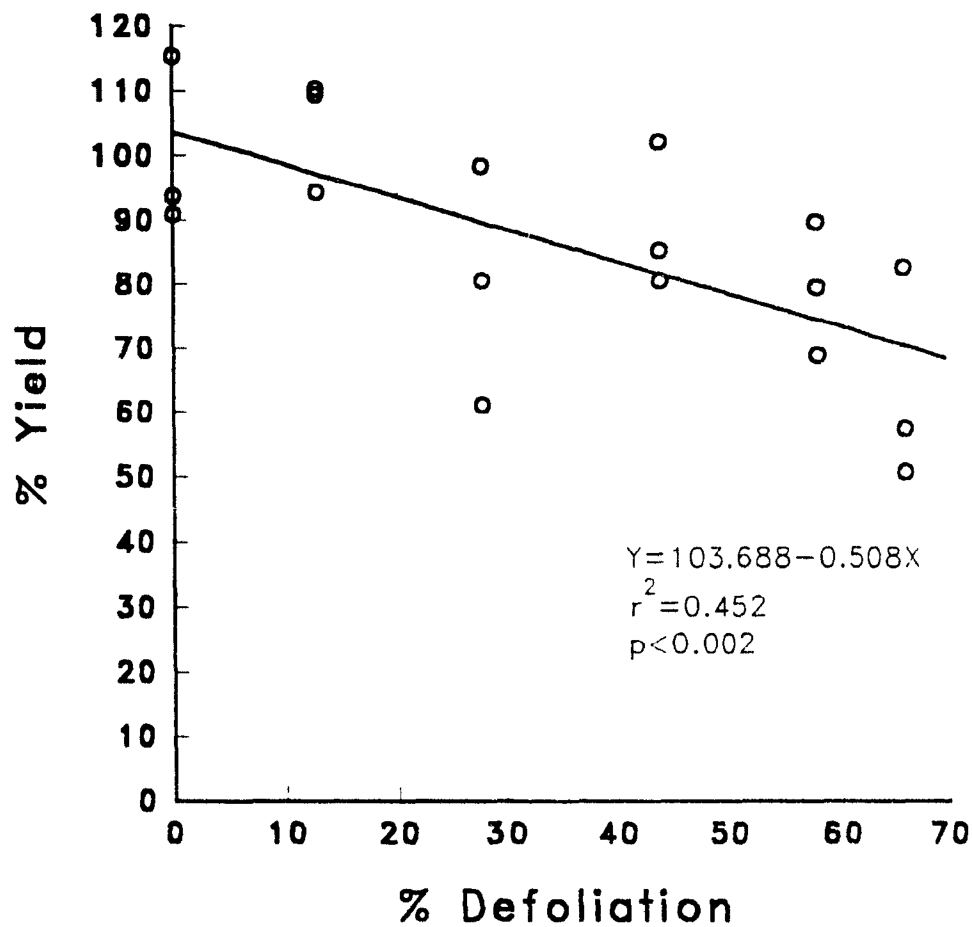


Figure 10: Relation between percent artificial defoliation (X) at R5 growth stage on Roan soybean cultivar, and percent yield (Y). Parameter estimates obtained from Table 14.



<u>Figure 11:</u> Relation between percent artificial defoliation (X) at R5 growth stage on SCS1 soybean cultivar, and percent yield (Y). Parameter estimates obtained from Table 14.

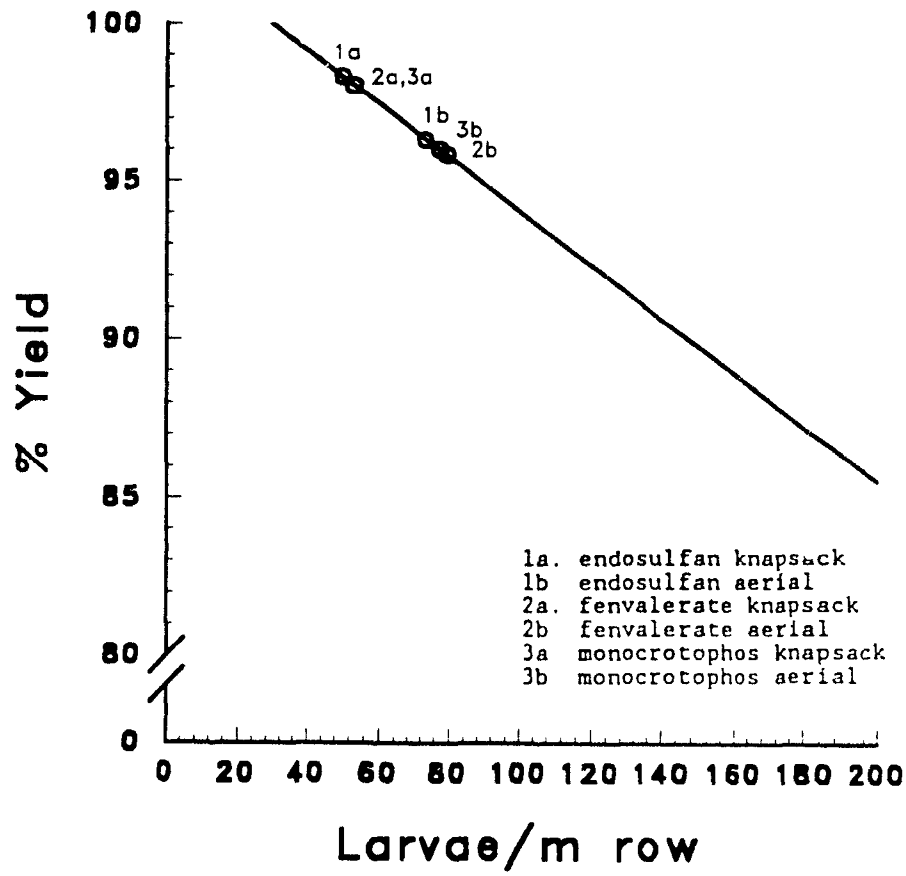


Figure 12: Relation between captures of semilooper caterpillars (X) (using ground cloth technique) one day before R2 soybean growth stage on Duiker soybean cultivar and percent yield (Y). Data given in Table 37.

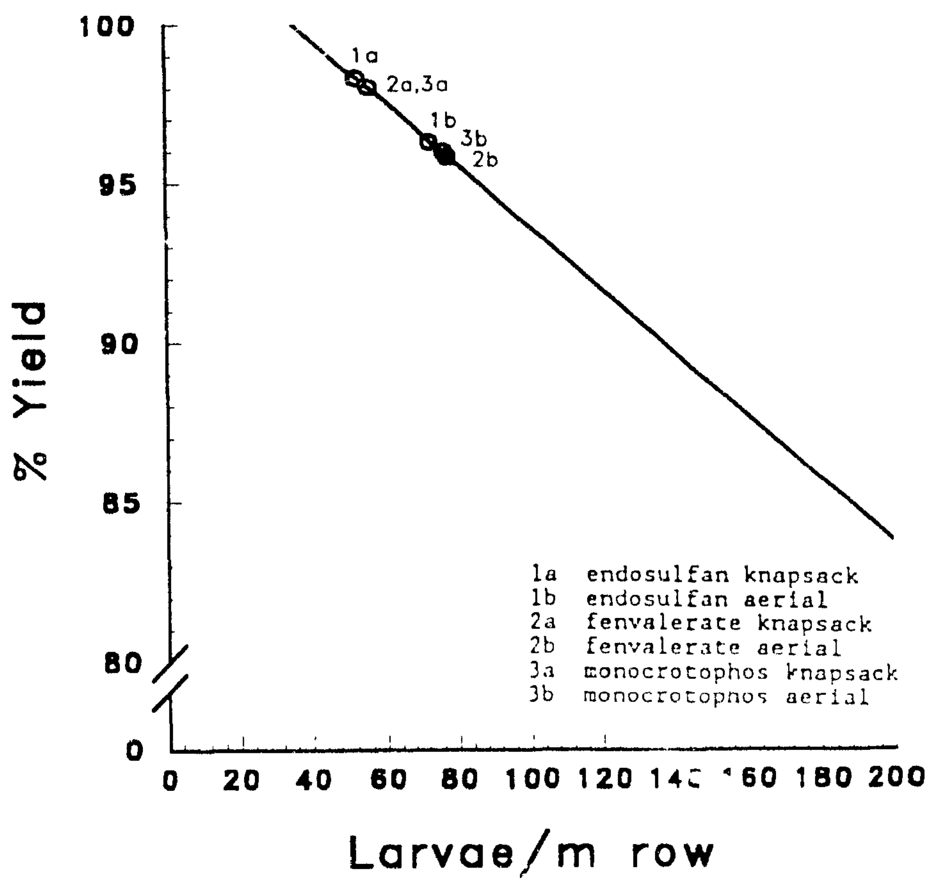


Figure 13: Relation between captures of semilooper caterpillars (X) (using ground cloth technique) one day before R3 soybean growth stage on Duiker soybean cultivar, and percent yield (Y). Data given in Table 37.

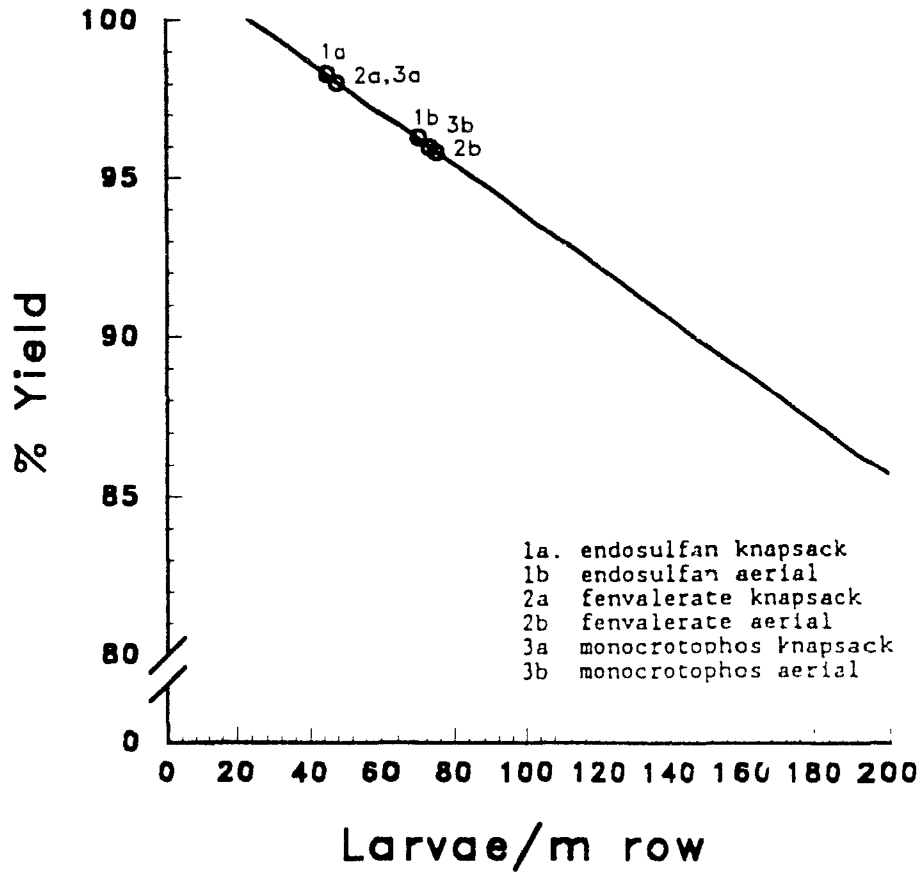
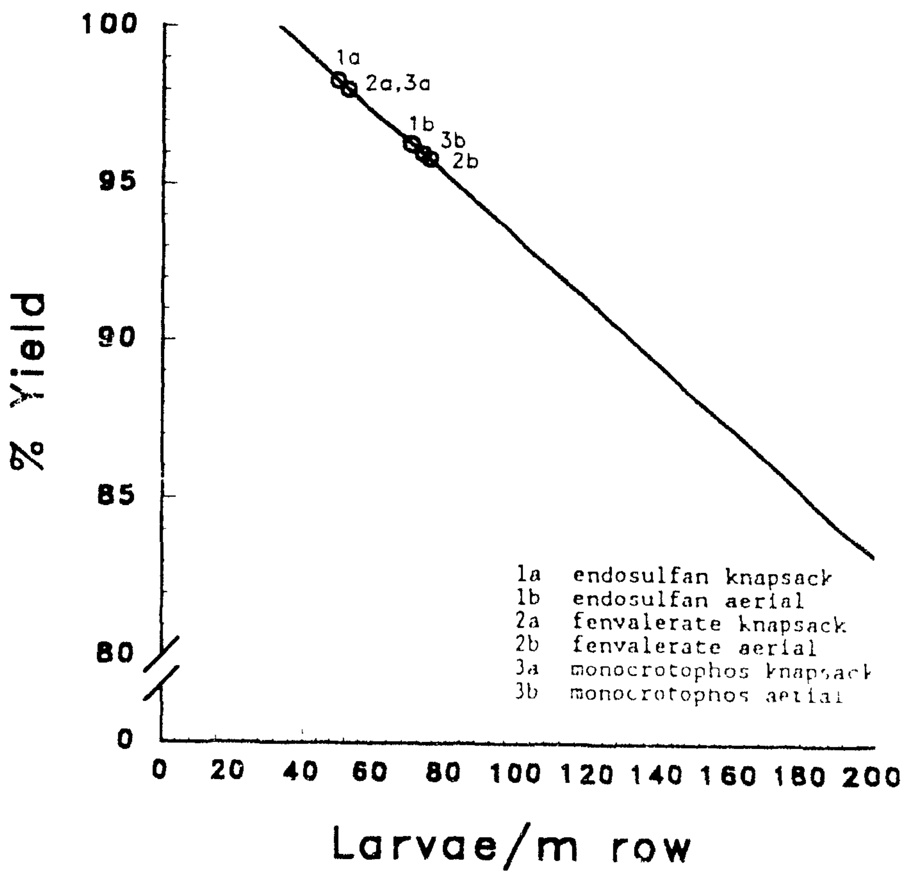


Figure 14: Relation between captures of semilooper caterpillars (X) (using ground cloth technique) one day before R3 soybean growth stage on Roan soybean cultivar, and percent yield (Y). Data given in Table 37.



<u>Figure 15:</u> Relation between captures of semilooper caterpillars (X) (using ground cloth technique) one day before R5 soybean growth stage on Duiker soybean cultivar, and percent yield (Y). Data given in Table 37.

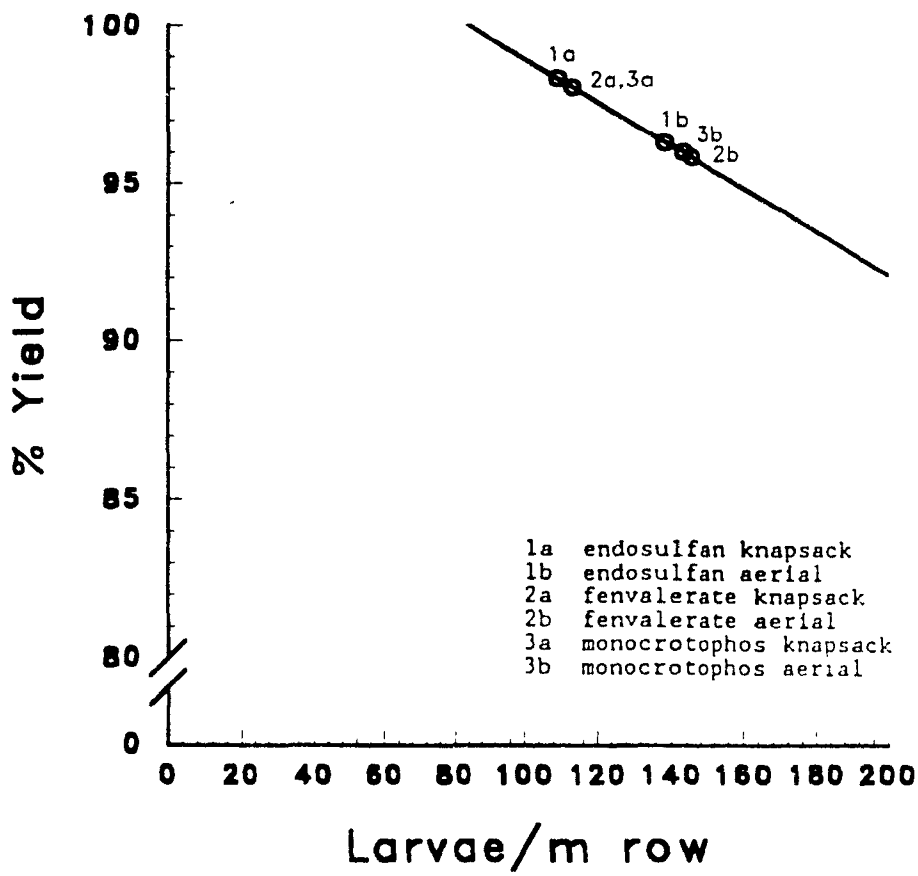


Figure 16: Relation between captures of semilooper caterpillars (X) (using ground cloth technique) one day before R5 soybean growth stage on Gazelle soybean cultivar, and percent yield (Y). Data given in Table 37.

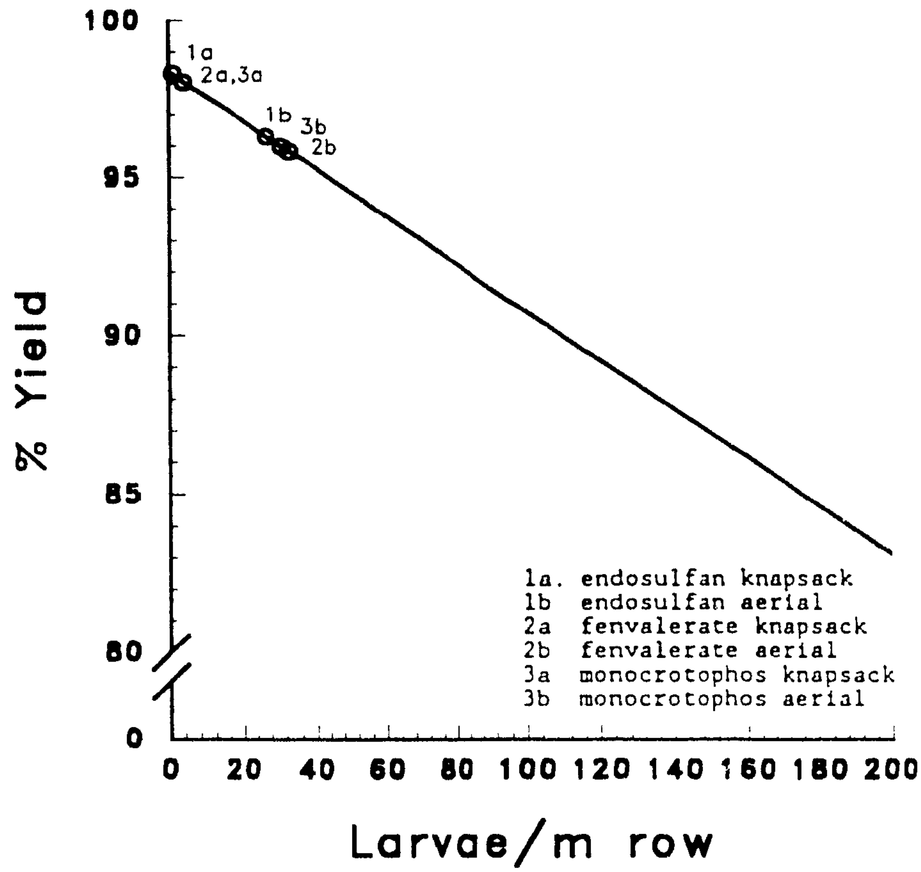


Figure 17: Relation between captures of semilooper caterpillars (X) (using ground cloth technique) one day before R5 soybean growth stage on Roan soybean cultivar, and percent yield (Y). Data given in Table 37.

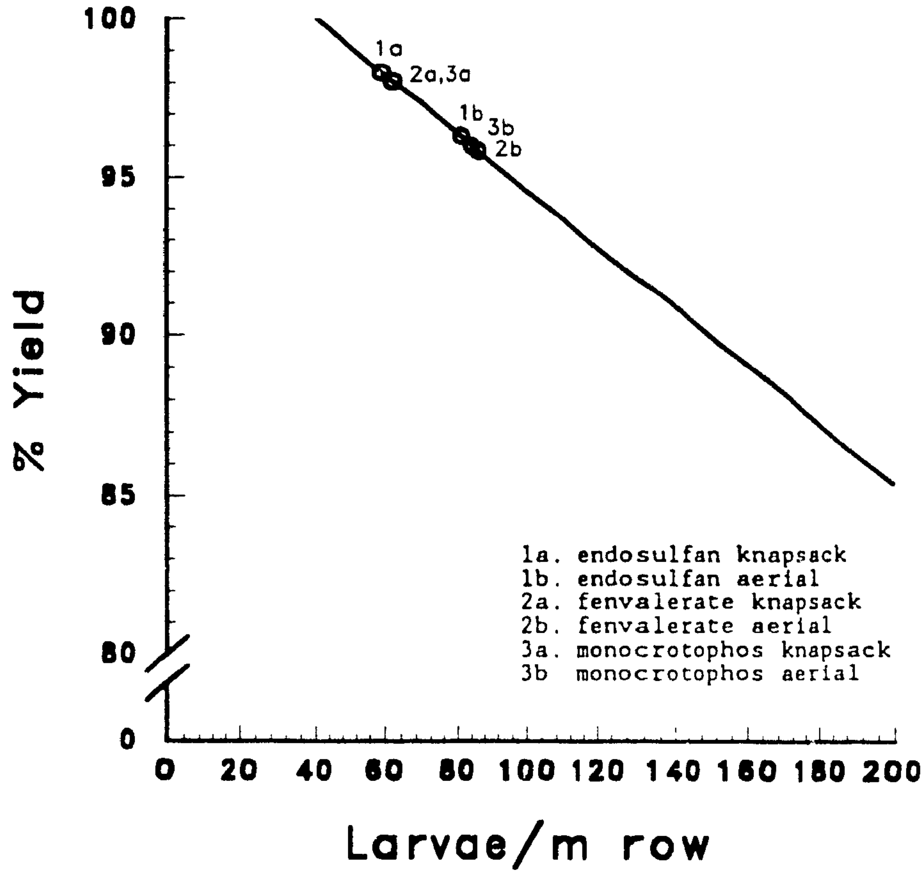


Figure 18: Relation between captures of semilooper caterpillars (X) (using ground cloth technique) one day before R5 soybean growth stage on SCS1 soybean cultivar, and percent yield (Y). Data given in Table 37.

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Appendix I: Chemical names of pesticides used in field experiments.

Agral®: Nonylphenolethylene oxide condensate.

Carbaryl®: 1-Naphthyl N-methylcarbamate.

Dual®: 2-chloro-N-(2-ethyl-6-methylphenyl)-N-(2-methoxy-1-methylethyl) acetamide).

Karate®: ∝-cyano-3-phenoxybenzyl 3-(2-chloro-3, 3, 3-trifluoroprop-1-enyl) -2, 2-dimethylcyclopropane ecarboxylate.

Thiodan®: 6,7,8,9,10,10-Hexachloro-1,5,5a,6,9,9a-hexahydro - 6,9-methano -2,4,3- benzodioxathiepin -3- oxide.