INTERACTIONS BETWEEN THE BLACK BEAN APHID *APHIS FABAE* SCOPOLI (HOMOPTERA: APHIDIDAE) AND THE HOST PLANT *PHASEOLUS VULGARIS* L.

by

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DECLARATION

This thesis is my original work and has not been presented for a degree in any other University.

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This thesis has been submitted for examination with my approval as University Supervisor.

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D E D I C A T E D

TO MY BELOVED PARENTS

LAPWONY CECILIO W. LATIGO

and

MAMA ANTONIETTA ANEK

TO MY DARLING WIFE

LUCY

and

TO MY DEAR BROTHER

BRO. ALEX KOKO

IN HUMBLE APPRECIATION OF THE ROLES THEY HAVE PLAYED AND CONTINUE TO PLAY IN MY LIFE.

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SUMMARY

Aspects of the biology of _Aphis fabae_ Scop. on the host plant _Phaseolus vulgaris_ L. were investigated. Greenhouse studies were also conducted to assess the influence on the performance of common beans of the levels of _A. fabae_ infestation, stage of bean development at which the infestation occurred, aphid transmission of Common Bean Mosaic virus, and the levels of soil moisture and soil fertility. The biological performance of _A. fabae_ on ten different varieties of common beans was also assessed.

The mean duration of _A. fabae_ nymphal development on Red Haricot and Mwezi Moja varieties of beans was 7.8 days when the nymphs developed into wingless adults, and 9.5 days when they developed into winged adults. The duration of instar stages was also similar on both varieties of beans.

Aphid larviposition fluctuated during the day, and significantly ($P - 0.05$) more nymphs were produced in the early morning than during the other periods of the day. The mean number of progeny produced during the reproductive life of each mother aphid was 55.2 nymphs on Mwezi Moja variety and 56.2 nymphs on Red Haricot variety. The duration of

aphid larviposition extended over a mean period of 15.3 days and ranged between 11 and 17 days.

A. fabae populations developed more rapidly from higher initial levels of infestation than from lower ones. After 16 days of reproduction, the ratio of number of aphids per plant from initial infestations of two, four and eight adults per plant was 1:2:3 instead of 1:2:4 at the start of infestation. A very rapid rate of aphid population increase was indicated.

Damage to bean growth, development and yield was severe when *A. fabae* were infested to beans at the early vegetative and late vegetative stages of development. Smaller, but significant reduction in yield also occurred when aphids attacked bean crops at the anthesis stage of development. The higher level of aphid populations was more harmful than the lower level, especially when aphid attack occurred at the early vegetative and late vegetative stages of development. Damage from infestation at the grain filling stage was minimal.

When *A. fabae* transmitted Common Bean Mosaic virus, the disease developed on plants infested with the aphids at the early and late vegetative stages of development, and the combination of the disease and aphid attack resulted in very severe damage to the plants. Beans infested at the anthesis stage also suffered serious damage, but the effect of the virus was less pronounced.

Both low levels of soil moisture and soil fertility resulted in highly significant (P = 0.01) reduction in the growth, and yield of beans, and increased the degree of damage caused to the plants by aphid attack.

The assessment of bean damage indicated that the most important A. fabae attack in terms of injury to beans and the transmission of plant virus diseases are those that occurred during the vegetative stages of development. Aphid damage was minimised by good levels of soil moisture and fertility for bean growth.

The incidence of A. fabae on field planted beans varied with the cropping season. It was very low (<2.0%) during the dry period between January and April, and also at the start of the long rains. There was a marked increase in aphid incidence during June, July and August, and over 80% infestation was observed. This indicated the high potential for aphid damage to late planted crops.

The biological performance of *A. fabae* varied on the different varieties of beans tested. There were significant ($P \leq 0.05$) variations in the duration of nymphal development, mortality of nymphs, the build-up of aphid populations, and field colonisation among the ten varieties of beans. The varieties Canadian Wonder, Pink Rose Coco, Zebra Beans and Red Haricot were more harmful to the aphids, and therefore possessed most resistance to the pest, whereas the varieties Mwitemania, Small White Rose Coco, Mwezi Moja and Large White Rose Coco were the least harmful, and therefore possessed the least resistance to *A. fabae*.

The study showed that aphid-bean interactions were influenced by various aphid, bean and environmental factors.

CHAPTER 1

INTRODUCTION

1:1 Grain legumes and their importance.

Grain legumes refer to leguminous plants producing seeds primarily consumed by man or known to be edible (Stanton, 1966). The designation "grain legumes" or "pulses" is generally restricted to leguminous plants producing dry edible seeds, although the fresh pods, fresh seeds, green leaves, shoots, flowers and tuberous roots of the same plants may also be edible (Okigbo, 1976). Grain legumes are characterised by the high protein content and nutritive value of their seeds.

Ten species of grain legumes are cultivated in different parts of the tropics, depending on altitude, latitude and rainfall (Rachie and Roberts, 1974). Those grown in East Africa include *Phaseolus vulgaris* L. (Common bean), *Cajanus cajan* L. (Millsp.) (Pigeon pea), *Vigna unguiculata* (L.) Walp. (Cowpea), *V. mungo* (L.) Hepper (black gram), *V. radiata* (L.) Wilczek (green gram), *Cicer arientum* L. (chick pea) and *Glycine max* (L.) Merr (Soybean)

(Purseglove, 1968). Common bean (P. vulgaris) is the most important grain legume in Kenya. In the 1974/75 crop estimates it covered over one half of the total land area under pulse crops (Anon., 1979 a).

The importance of legumes lies in the fact that they are major sources of vegetable protein of high biological value, energy, minerals, vitamins and roughage. They are also used as sources of vegetable oil and livestock feed, and as green manure and erosion control (Okigbo, 1978; Okigbo, 1976). In addition the roots possess nodules containing rhizobia that are capable of fixing nitrogen (Okigbo, 1976; Okigbo, 1978).

In many tropical developing countries including Kenya, legumes supply a high proportion of the plant proteins which are not only the main, but also the cheapest source of proteins in areas where animal proteins are too scarce and too expensive for a large proportion of the population (Okigbo, 1978). Grain legumes have a higher food value and nutrient balance than the major starchy staples (Anon., 1964). In comparison with beef (lean) and fish (white sea), most legumes including common beans have a higher calorific value, greater per cent crude protein and carbohydrate, and a higher content of the minerals calcium and iron, and the amino acids thiamine and riboflavin (Anon. 1964).

Grain legumes form an important component in tropical cropping systems. The nitrogen-fixing ability of grain legumes is of special advantage in subsistence agriculture on small farms where fertilizers are little used (Okigbo, 1976, Singh and van Emden, 1979). An intercrop of maize and Phaseolus beans has been shown to improve crop yield and land productivity (Willey and Osiru, 1972; Osiru and Willey, 1972). This is mainly because of better environmental resource utilization, improved soil cover resulting in moisture conservation and increased rain erosion control, and, increased soil fertility through nitrogen fixation.

1:2 Phaseolus bean production and yield constraints in Kenya.

In Kenya grain legumes particularly common beans constitute the most important group of food crops apart from maize (Anon. 1974a). The production of common beans varies from province to province in Kenya. In this country, over 99% of the crop are produced by small scale farmers mainly for subsistence, and only small acreages of beans are planted for canning, mainly for export (Schonherr and Mbugua, 1976). The common beans are mainly intercropped with other crops such as maize, sorghum and cassava (Anon. 1979a).

The yield of common beans in Kenya are highly variable for a number of reasons. These reasons include the region where the crops are cultivated, time of planting, the variety or cultivar grown, the incidence of pests and diseases, and the cultural practices and crop protection measures employed (Schonherr and Mbugua, 1976). These workers reported that the national bean yields averaged 500 kg/ha, and ranged from 180 kg/ha to 1350 kg/ha. They partly attributed these low yields to severe insect damage including the damage caused by the Black Bean aphid, Aphis fabae Scopoli. It has been shown that with good crop production methods, including sound plant protection measures applied against pests, high yields ranging from 1283 kg/ha to 3549 kg/ha could be realised in Kenya (Anon. 1974b). This indicates that insect pests, notably aphids, are major constraints to obtaining higher yields.

The Black Bean aphid is a serious pest of several species of legumes and it also attacks a very wide range of other crop plants and weeds (Hill , 1975). It is widespread in the highland regions of East Africa and is believed to have been introduced from temperate Europe (Eastop, 1953). In Uganda it is found commonly above 1,000 meters and is particularly serious in the south-western region where it causes severe damage to beans (Ingram, 1969; Nyiira, 1978). In this region in Uganda yield losses of upto 90% have been known to occur (Nyiira, 1978).

Aphids are primarily controlled by using systemic insecticides. Recommended standard aphicides include phorate, disulfoton or menazon as preventive treatments, and demeton-s-methyl or oxydemeton methyl as eradicant sprays (Hill, 1975). However these chemicals are known to pose serious hazards to pollinators, parasites and predators (Ingram 1969; Way, 1961). Chemical control entails the danger of insecticides aggravating aphid problems on grain legumes in the tropics since the pest is often kept under check or is reduced by a large number of parasites and predators (Singh and van Emden, 1979).

Delayed application of the aphicides also seriously reduce their effectiveness, and the resultant increased number of application required may not be economical (Ingram, 1969). Hence, although efficient insecticides are available, varietal resistance is desirable both in helping to stabilize yields where chemicals cannot be applied, and to reduce production costs and hazards to beneficial insects (Bond and Lowe, 1975).

The studies reported here were an attempt to understand the basic interactions between the bean aphids A. fabae and their host, P. vulgaris, and to determine the magnitude of bean damage associated with the various levels and time of aphid attack. Investigations were also conducted to evaluate aphid biological performances on several bean varieties which are currently grown by farmers in Kenya. It was hoped that the findings of these studies would contribute to a better understanding of the aphid pest of common beans. This would help to improve aphid pest management on beans and on other grain legumes in general. It was also hoped that the studies would provide preliminary information on A. fabae resistance in beans which could be useful in the development of common bean varieties resistant to the pest.

CHAPTER 2

LITERATURE REVIEW

2:1 Introduction.

In East Africa, published studies on the aphid A. fabae are basic in character and they include Eastop (1952, 1953, 1954, 1957) Wallace (1939, 1941), Ingram (1969), Kulkarni (1972), and Kaiser (1976). These works reflect some lack of emphasis on the importance of the insect as a pest of pulse crops. Khamala (1978) noted that apart from casual observations and reports from farmers and agricultural extension workers, very little was known about insect pests of grain legumes, including A. fabae in Kenya. From their studies of the effect of A. fabae on the growth and yield of field beans (Vicia faba L.), Way et. al. (1954) concluded that there was need to expand work both on A. fabae damage assessment and methods of control. Such studies have not yet been carried out in Kenya.

2.2 Aphis fabae biology.

Aphids produce both sexual morphs as well as parthenogenetic virginophareae; this is especially so in temperate regions, and sexual forms have not been reported in the tropics (Dixon, 1978). The aphids also develop into winged and wingless adults. The alate forms are known to develop in response to such diverse factors as crowding, deterioration of the quality of the host plant, availability of attendant ants, temperature, photoperiod, and intrinsic factors (Dixon, 1978).

The development and performance of A. fabae is affected mainly by temperature and the nature and condition of the host plant (Davidson 1925; Kennedy et. al., 1950; Ibbotson and Kennedy 1951; Kennedy and Booth 1954; Johnson et. al., 1957a, 1957b). The factors that affect the growth and the nutrient conditions of the host plants are also known to affect A. fabae development indirectly (Davidson, 1925; Kennedy, 1958; Waghray and Singh 1965).

Davidson (1925) carried out biological studies of A. rumicis L. (= A. fabae) on V. faba under differing conditions of temperature, light intensity and manurial treatments by infesting young growing plants with aphids and observing the performance of their progeny. He found that with a mean temperature of 58^{o}F during the reproductive period, the "developmental period" - which is the time a nymph was born until it began larvipositing - of the aphid averaged 11 days; the average daily production of the young by the asexual females was four; and the average total number of young produced by one female was 52. He further observed that the "developmental period" decreased with increased temperature. For example at a mean temperature of 64^{o}F the "developmental period" was 10-12 days while it was eight to ten days at a mean temperature of 70^{o}F. It has been suggested that a generation of A. fabae could take as short a time as seven days (Hill, 1975). This implies that an extremely rapid rate of increase of the insect can occur under field conditions.

It has been established in some studies that A. fabae prefers and reproduces more on the young growing leaves and shoots than on middle aged static leaves of some host plants (Davidson, 1925; Kennedy *et. al*., 1950; Ibbotson and Kennedy, 1951; Kennedy and Booth, 1950, 1954). In their experiments Kennedy and Booth (1954) reared *A. fabae* on young and on mature old leaves of sugar beet, and found that twice as many nymphs were produced on young leaves as compared to mature leaves.

In studying the reproductive and developmental biology of *A. fabae* on common beans an attempt was made in the current work to obtain biological information of the aphid that would serve as a basis for screening for aphid resistance of various bean varieties or cultivars. This would enable eventual identification, selection and breeding of varieties resistant to the aphids.

2:3 Plant damage by *A. fabae*

The bean crop may be infested with several aphid species. Hill (1975) listed *Acyrthosiphon pisum* Harris, *A. fabae*, *Aphis gossypii* Glover and *Aphis craccivora* Koch as attacking legumes, including common beans in the tropics. Kulkarni (1972) collected a wide range of aphids from bean fields in the Kenya Highlands and found that only A. *fabae* and A. *gossypii* were associated with beans as vectors of the Bean Common Mosaic virus.

The aphids usually attack the bean plants by sucking sap from the stems, young leaves and shoots. Damage caused is three fold, being direct loss of plant sap, mechanical injury to plant tissue during feeding and introduction of virus diseases (Hill, 1975). Hill (1975) described general damage to beans by A. *fabae*. He noted that infested leaves were often cupped or otherwise distorted and more or less yellow and the crop generally stunted. Such attack could be a serious check to growth resulting in loss of yield (de Pury 1968). Assessment of the effect of A. *fabae* attack on the growth and yield of beans in Kenya has not been carried out. However attempts have been made elsewhere to assess the effect of A. *fabae* attack on field beans *V. faba* (Judenko *et. al.*, 1952; Way *et. al.*, 1954).

In their study of field planted beans, Judenko *et. al.* (1952) found that the attack of *A. fabae* on *V. faba* in the field resulted in significant reduction in mean total stem length per plant, and that reduced seed yields were due to fewer pods per plant, fewer seeds per pod, with smaller bean seeds for infested plants as compared to uninfested ones. In a study conducted by Way *et. al.* (1954) similar damage effects were observed. These workers found that aphid abundance caused almost all developing pods to drop or shrivel before reaching maturity. They also found that yield and quality of seeds were affected and that infested plants produced fewer and smaller seeds.

The studies by Judenko *et. al.* (1952) and Way *et. al.* (1954) reported above did not relate plant damage to a defined level of *A. fabae* infestation, and they did not also relate plant damage and yield losses to aphid infestation at various stages of plant development. Such information is desirable in determinig the economic injury levels and establishing a suitable basis for aphid management and control. Experiments conducted during the current studies were designed to obtain this information.

Aphids do not only damage crop plants directly but also transmit plant viruses. It is known that more plant viruses are transmitted by aphids than by any other group of insects (Swenson, 1968). Evidence has accumulated indicating that aphids sometimes do more damage by transmitting viruses than by removing plant sap (Dixon, 1978). He also reported that viruses are carried by migrating aphids which may travel as far away as 1,300 km., thus resulting in extensive spread of the diseases.

Kennedy <u>et</u>. <u>al</u>. (1962) distinguished two groups of viruses, namely, "stylet-borne" and "circulative" viruses. Stylet-borne viruses are carried inside the labial groove and because they are transported on the stylet tips the infectivity of the insect is lost following a moult and are therefore non-persistent (Mathews 1970). Circulative viruses when ingested by the aphid pass through the hemocoele from which it can be recovered to the salivary glands. This type of infectivity is not lost following a moult, and as such the viruses are persistent (Mathews, 1970).

The transmission of viruses from plant to plant is bi-modal. Stylet-borne viruses are mechanically transmitted as the insect stylet penetrates the host tissue (Lim and Hagedorn, 1977). A minimum of probing is sufficient for the aphids to acquire and transmit the virus (Mathews, 1970). In the case of circulative virus a certain amount of time - the latent period - must elapse after acquisition before the insect can effectively transmit the virus so acquired (Lim and Hagedorn, 1977).

The bean aphid A. fabae is known to transmit over 30 different plant viruses (Hill, 1975). Bean Common Mosaic virus and Bean Yellow Mosaic virus both of which are stylet-borne are the two most important viruses transmitted by A. fabae to beans in E. Africa (Kaiser, 1976; Kulkarni 1972; Wallace

1941, 1939). Bean Yellow Mosaic virus is reportedly not seed borne (Wallace, 1941; Kulkarni 1972; Smartt, 1976). However, Kaiser (1975) observed that the virus in his experiments was seed transmitted in 80% of the bean lines tested. Bean Common Mosaic virus is seed transmitted; the transmission is irregular and varies from 30 to 50% (Smith, 1972). In case of most infections that occur after flowering, the virus does not reach the seed (Nelson, quoted by Smith, 1972). A. fabae seems to be a mechanical vector only of the virus and other aphid species are therefore likely to be capable of transmission (Smith, 1972 ; Zettler, 1967).

The symptoms of Common Bean Mosaic on Phaseolus beans vary a great deal depending on the variety of beans infected, time of virus infection and the environmental conditions (Smith, 1972). Affected leaves show, in general various degrees of mottling and chlorosis, downward cupping of the laminae, puckering and blistering. Mosaic leaves may be smaller than healthy ones and very much more distorted. On the less susceptible varieties a ruffling and crinking of the leaves is characteristic of the disease, and these may be accompanied by a general chlorosis of the leaves with pronounced venation. In addition the affected plants are characterised by a shortening of the petioles, general stunting of the plants and deformation of pods and flowers and the plants may be unproductive (Smith, 1972; Wallace, 1941).

2:4 Plant resistance to insects.

The resistance of plants to insect pest attacks has been generally defined as the relative amount of heritable qualities possessed by the plant which influence the ultimate degree of damage done by a pest (Snelling, 1941; Painter, 1951, 1958; Beck (1965). In their studies of resistance Painter (1951), Pathak (1970), and Singh (1978) laid emphasis on the degree of plant damage, whereas Beck (1965) underscored the importance of the biological relationship involved. Khaemba (1980) has pointed out these differences in emphasis.

Painter (1951) classified the mechanisms of plant resistance to insects as preference or non-preference, antibiosis and tolerance. A plant is non-preferred when it possesses characters that render it unattractive to insects for oviposition, food, shelter, or for combinations of these three (Painter, 1951). After reviewing the factors that constituted preference or non-preference Dethier (1954, 1970) concluded that insects followed a chain of conditional responses to plant stimuli in finding their host for shelter, food or larviposition.

Antibiosis denotes those adverse effects on the pest life history which result when the pest used a resistant host plant variety or species for food (Painter, 1951; 1958). Antibiosis has been classified by Beck (1965) as either biophysical or biochemical. Thes biophysical resistance was antibiosis due to plant physical factors such as pubescence, epidermal trichomes and tissue thickness. Whereas biochemical resistance was antibiosis resulting from the presence of toxins, and lack or inbalance in some essential nutritional materials in resistant plants, which adversely influenced physiological processes pertaining to growth, metamorphosis and reproduction of the insects. The effects of antibiosis on the pest may take the form of reduced fecundity, decreased size, abnormal length of life and increased mortality (Painter, 1951).

Tolerance is a basis of resistance in which the plant shows an ability to grow and reproduce itself, or to repair injury to a marked degree in spite of supporting a pest population equal to that damaging a susceptible host (Painter, 1951). Both Painter (1951) and Horber (1972) have pointed out that tolerance was present most often in connection with the feeding of insects with sucking mouth parts. It has also been suggested that tolerance as a mechanism of resistance was more subject to environmental variation than antibiosis and preference or non-preference (Horber, 1972).

Studies have shown that resistance to insect pest in a plant depends upon the insect pest, the plant host and the environment (Painter, 1951, 1958; Beck, 1965; Hober, 1972). Painter (1951) listed the main insect factors influencing the expression of resistance as abundance (population), activity (feeding, oviposition), and transmission of plant diseases; while the plant factors enumerated included physical structures (trichomes), hybrid vigour, chemical composition, disease susceptibility, sensitivity to insect feeding, and maturity. He also listed the environmental factors as being climatic (humidity, temperature and light), soil (moisture and fertility), and agronomic (cultivation techniques, crop spacing, weed control).

Insect resistant crop varieties provide an ideal method of controlling or suppressing insect damage to crops. Resistance has several advantages over other methods of pest control. It involves minimum production costs, does not harm beneficial insects (pollinators, parasites and predators) and is compatible with biological, chemical, cultural and other control methods (Horber, 1972). It has also been suggested that host resistance could increase the effectiveness of natural enemies of pests and thus delay economic damage levels in crops (van Emden and Wearing,1965; Johnson,1953).

The resistance of field beans (*V. faba*) to *A. fabae* has been investigated by several workers (Davidson and Fisher,1922, Tambs-Lyche and Kennedy, 1958; Muller,1958; Banks and Macaulay, 1970; Bond and Lowe,1975). Davidson and Fisher (1922), assessing *A. fabae* reproduction on field beans found various grades of susceptibility ranging from 98.0% to 3.0%, and concluded that resistance or susceptibility was largely determined by genetic factors. In their investigations, Bond and Lowe (1975) found that fewer adult aphids settled on plants of resistant varieties, and that there was a smaller build-up of *A. fabae* colonies on the resistant varieties.

Studies on the resistance of common beans *P. vulgaris* to *Aphis* species have also been reported by several workers (Pillemer and Tingley, 1976;

Steinmetz and Arny, 1932; MacKinney, 1938; Johnson, 1953). These workers emphasised the injurous effects of epidermal hairs on the pests, which resulted in increased length of larval development, high nymphal mortality and reduced population growth. Such studies, to ascertain whether there are any varieties of common beans currently grown by farmers in Kenya that are resistant to A. fabae have not however been reported. Since resistance is a highly desirable attribute of pest-host relationship, the identification and development of A. fabae resistance in common beans would greatly improve the management and control of the pest in Kenya.

2.5 Objectives of the study.

The objectives of this project were to carry out studies on the following:

a) The biology of bean aphid A. fabae on common beans P. vulgaris:-
   - nymphal development
   - larviposition and fecundity
   - population development.

b) Damage and yield losses of common beans *P. vulgaris* caused by the bean aphid *A. fabae* at the following stages of plant development:-

- early vegetative
- late vegetative
- anthesis
- grain filling.

i) evaluate the effects of two levels of *A. fabae* infestation on beans at four stages of plant development.

ii) evaluate the effects of two levels of *A. fabae* infestation, transmission of Common Bean Mosaic virus, and the stage of plant development on the growth and yield of common beans *P. vulgaris*.

iii) evaluate the influence of two levels of soil moisture and soil fertility, and, *A. fabae* infestation at four stages of plant development on the growth, reproduction and yield of common beans.

c) Field seasonal incidence of A. fabae and the biological performance of the aphid on some important varieties of common beans P. vulgaris.

i) study the seasonal incidence of A. fabae on common beans in the field.

ii) assess the effects of plant host on the development, reproduction and survival of A. fabae when reared on ten major varieties of common beans grown by farmers in Kenya.

CHAPTER 3

GREENHOUSE STUDIES ON THE BIOLOGY OF THE BLACK BEAN APHID *A. FABAE* ON COMMON BEANS *P. VULGARIS*.

3:1 INTRODUCTION.

The study of the biology of bean aphids *A. fabae* is regarded as an important first step in the evaluation of the relationship between the pest and the host plants (Van Emden, 1972). In their studies on tests of resistance of field beans *V. faba* to the bean aphids, resistance or susceptibility of beans was partially indicated by the relative differences in the biological performance of *A. fabae* on the various host lines tested (Bond and Lowe, 1975). As part of the present studies a similar assessment was undertaken when the biological performance of *A. fabae* was evaluated on some of the important bean varieties and cultivars commonly grown in Kenya.

The main objective of the biological studies reported here was therefore to assess the various aspects of the biology of the pest when reared on common beans that may be useful in evaluating their biological performances on different varieties or cultivars of the crop. The other objective of these studies was also to gain additional knowledge of this important pest of common beans and other legumes in Kenya.

3:2 MATERIALS AND METHODS

3:2:1 General procedure

Experiments were conducted in the greenhouse at the University Farm, Field Station, Kabete Campus, to study some aspects of the biology of A. fabae on the common bean plants. The bean varieties used in the studies were Mwezi Moja (GLP.10), and Red Haricot (GLP. 3). These two varieties were selected because of their contrasting growth characteristics; Mwezi Moja is a determinate bush-type while Red Haricot is a climbing type. The seedlings of these varieties were raised in plastic pots (top diameter 20 cm). Five seeds were planted in each pot and the seedlings thinned to two or three per pot one week after emergence.

The potting soil used for growing the plants consisted of fine brown sand. The brown sand used in these experiments was steam sterilized then thoroughly washed in tap water to remove soluble plant nutrients. Processing of the sand in this manner was necessary so that the addition of known amounts of plant nutrients would result in a uniform nutritional status of the plants, thus diminishing plant variability due to soil nutrient regimes (Davidson, 1925; Wayhray and Singh, 1965). A solution of 5.0g NPK (20: 20: 20) fertilizer dissolved in one litre of water was supplied to plants at the rate of 50 mls per pot per week in order to provide a uniform nutrient regime.

A. fabae test insects used in these experiments were reared using a simplified "production line" technique described by Kennedy and Booth (1950). Mature *A. fabae* were initially obtained from field populations of the pest infesting common beans. They were then fed on seedlings of the variety Mwezi Moja in the greenhouse from which parasites and predators were excluded. After three days of larviposition the mother aphids were removed and their progenies left to develop and multiply. This method allowed for large numbers of individuals of A. fabae to be raised which were healthy and unparasitised. Freshly moulted A. fabae adults obtained from the greenhouse colony were used to infest experimental plants by transferring them with a wet camel's hair brush as described by Van Emden (1972). The plants were infested in their early vegetative growth stage (upto two weeks after emergence) as this stage is known to be the most ideal for aphid development and multiplication (Davidson, 1925; Johnson et. al., 1957a).

3:2:2 Studies on the "development period" of the bean aphid A. fabae on common beans P. vulgaris under greenhouse conditions.

This experiment was conducted so as to obtain information on the "developmental period" of A. fabae when fed on common beans, which is their main host, under greenhouse conditions. The "developmental period" was defined by Davidson (1925) as the period from when the young aphids are born until when they start to reproduce.

Five pots each of which contained three uniformly growing bean seedlings were selected for the varieties Mwezi Moja and Red Haricot immediately after the plants had been thinned. These plants were then tagged and each of them infested with two freshly moulted A. fabae adults. The aphids were allowed to reproduce for a period of three hours and then removed leaving only two of the nymphs produced per plant to grow and develop. This procedure ensured that the test insects left to continue feeding and developing on the plants were uniform in age.

Everyday the nymphs on each plant were inspected at intervals of two hours for twelve hours starting from 06.00 hrs, to 18.00 hrs. The day and approximate time of moulting of each nymph was recorded. This observation was continued for each nymph up to its first larviposition. From this data, the duration of each instar period, and the length of period from birth to first larviposition, being the "developmental period" for test insects was calculted.

3:2:3. Studies on the larviposition and fecundity of the bean aphid *A. fabae* on common beans *P. vulgaris* under greenhouse conditions.

Experiments were conducted to obtain information on the larviposition and fecundity of *A. fabae* on common beans under greenhouse conditions. It was felt that this information would be useful in indicating the potential productivity of the aphids when fed on common bean varieties Mwezi Moja and Red Haricot.

For this purpose 10 pots each of which contained two uniformly growing bean seedlings were selected for each of the two bean varieties and infested with test insects. The two *A. fabae* adults on each bean seedling were allowed to reproduce for a period of three hours after which only three nymphs were left on each of the plants to grow and develop for a period of one week. At the end of this period (one week) two of the nymphs were removed from each plant so that only one mature aphid was left per plant.

In order to obtain data on the total number of progeny produced by each aphid on each bean variety used in these studies, ten aphids were inspected daily in the mornings between 09.00 hrs and 09.30 hrs. Nymphs produced by each aphid over a period of 24 hours were counted and then removed from the plants at the inspection time. These observations were conducted over a period of 21 days.

To ascertain the larviposition of A. fabae during day time nymphs produced by the aphids on ten Mwezi Moja seedlings were counted at intervals of two hours each day between 06.00 hrs and 18.00 hrs. These observations were recorded for ten times starting two days after the commencement of larviposition. At each inspection held every two hours newly produced nymphs were counted and recorded. At the final count for the day all the nymphs produced during the day (06.00 - 18.00 hrs) were removed from the plants. In the morning of the following day, the nymphs produced during the night time (18.00 hrs - 06.00 hrs) were counted at 06.00 hrs and then removed from the plants.

3:2:4 Studies on the population development of the bean aphid *A. fabae* on common beans *P. vulgaris* under greenhouse conditions.

The experiment was conducted so as to assess the build-up of *A. fabae* populations on common beans from three contrasting levels of initial infestation over a period of 16 days. The seedlings of the bean variety Red Haricot used in the experiment were of uniform growth and were thinned two weeks after planting to three seedlings per pot. Newly moulted *A. fabae* adults were placed onto the beans at three infestation levels as follows:

i) two aphids per plant
ii) four aphids per plant
iii) eight aphids per plant

Twenty four plants contained in eight pots were infested with aphids at each of the three population levels. The aphids were counted at intervals of two days, starting two days after the aphids had been infested onto the plants. On each day of counting, one pot was randomly removed for each level of aphid population and the aphids on the three plants growing in each pot counted.

3:3 RESULTS

3:3:1 The duration of the "developmental period" of the bean aphid *A. fabae* on common beans *P. vulgaris*.

The mean diurnal room temperature in the greenhouse during the course of the experiments reported here was 26.5°C and ranged between 15.0°C and 32.5°C. The results of the observations on the duration of the imature stages, and of the "developmental period" of *A. fabae* when fed on the bean varieties Mwezi Moja and Red Haricot are summarised in Table 1. It is shown by the results (Table 1) that the first nymphal instars of *A. fabae* when fed on bean variety Mwezi moja moulted after an average of 2.3 days (range 2.0 - 2.5 days) from birth, which was closely similar for nymphal instars fed on Red Haricot which moulted after an average of 2.2 days (range 2.0-2.5 days) from birth. The duration of the second nymphal instar of the aphids averaged 3.0 days (range 2.5-3.5 days) on both varieties of beans. On the variety Mwezi Moja the third nymphal instar took on average 2.5 days (range 2.0 - 3.5 days) before it started larvipositing, while those third nymphal instars fed on Red Haricot took an average of 2.6 days (range 2.0 - 3.5 days) before they started larvipositing.

It was shown in these experiments (Table 1) that the overall "developmental period" of A. fabae before they started producing young ones was 7.8 days on both Mwezi Moja and Red Haricot bean varieties. The range of duration of the three instar periods was also fairly similar on the two varieties. From these observations (Table 1) it was concluded that the two varieties of beans used in these studies were equally suitable as hosts of A. fabae with regard to the duration of their "developmental period".

It was also noted that the duration of the "developmental period" was 7.8 days only when A. fabae second nymphal instars developed into wingless adults. In the case where nymphal instars developed into winged adults, it was observed that the second nymphal instars developed over a longer period before moulting. In this case the duration of the second nymphal instars ranged between 4.0 and 5.5 days instead of between 2.5 and 3.0 days (Table 1) observed when the nymphs developed into wingless adults. The "developmental period" of winged A. fabae adults lasted on average 9.5 days and ranged between 8.0 and 10.5 days. Based on the observations that the "developmental period", which can also be regarded as the period required for one generation of A. fabae to develop was about 7.8 and 9.5 days for wingless and winged adults of the aphidsrespetively, it was estimated that 8-12 generations of A. fabae could develop on common bean crops lasting about three months in the field.

3:3:2 The larviposition and fecundity of the bean aphid A. fabae on common beans P. vulgaris.

The results on daily A. fabae larviposition presented in Table 2 showed that nymphs were produced both during the daytime (6.00 a.m. to 6.00 p.m.) and during the night period (6.00 p.m. to 6.00 a.m.). However, out of a mean daily nymphal

Table 1: The duration of nymphal instar stages and the "developmental period" of A. *fabae* on common beans *P. vulgaris* under greenhouse conditions.

bean varieties	instar stages	duration (days) of instar stages		
		mean	range	S.D.
Mwezi Moja (GLP. 2)	1st nymphal instar	2.3	2.0-2.5	0.18
	2nd nymphal instar	3.0	2.5-3.5	0.25
	3rd nymphal instar	2.5	2.0-3.5	0.31
	developmental period	7.8	7.5-8.5	0.24
Red Haricot (GLP. 3)	1st nymphal instar	2.2	2.0-2.5	0.18
	2nd nymphal instar	3.0	2.5-3.5	0.26
	3rd nymphal instar	2.6	2.0-3.5	0.33
	developmental period	7.8	7.5-8.0	0.21

SD = standard deviation

production of 13.0 nymphs, mean larviposition during the day (8.6 nymphs) accounted for 66.2% of the total number of nymphs produced by the aphids. It was also observed that most of the nymphs produced during the night were born in the early part of the night, between 6.00 p.m. and 8.00 p.m., and in the early morning, between 5.00 a.m. and 6.00 a.m., near daytime. Thus A. fabae larviposition on a given day mainly occurred during the day, and was associated with daylight period.

Mean nympal production by the aphids during the day varied from period to period for the six 2-hour periods (Table 2). The daytime variation in reproduction consisted of a high mean level of larviposition in the morning (Periods A and B) which declined in the early afternoon (Periods Cand D). Reproduction rose slightly in the mid-afternoon (Period E) and then declined in the evening (Period F). The rate of larviposition was therefore highest in the morning during Period A (= 2.2. nymphs) and lowest in the evening during Period F (= 0.8 nymph) (Table 2).

Comparison of the mean number of nymphs produced during the various 2-hour periods of the day revealed that aphid larviposition in the first two hours of the day, Period A, was significantly (P = 0.05) greater than during Periods C, D, and F, but was not significantly (P<0.05) different from larviposition during Periods B and E. Larviposition level during Period B was also significantly (P = 0.05) greater than in Period F. However, the mean number of nymphs produced during Periods C, D, E and F were not significantly (P<0.05) different from each other(Table 2). The results indicated that a consistently higher rate of larviposition occurred in the morning (periods A and B) which may be a characteristic feature of aphid reproduction rhythm during the day.

The number of progenies produced by A. fabae on common beans during the reproductive life of the mother aphids is given in Table 3. The duration of aphid larviposition extended over a mean period of 15.3 days, and ranged between 11 and 17 days. The production of progenies by aphids on the two varieties of beans used was similar, although slightly fewer nymphs were produced on Mwezi Moja than on Red Haricot variety.

The mean number of progeny produced by each

Table 2: The mean number of A. fabae nymphs produced on common beans, P. vulgaris during different periods each day under greenhouse conditions.

periods (time)		mean number of aphids produced
night time	(06.00 pm - 06.00 am)	4.3
daytime	(06.00 am - 06.00 pm)	8.6
period A	(06.00 am - 08.00 am)	2.2a
B	(08.00 am - 10.00 am)	1.8ab
C	(10.00 am - 12.00 am)	1.2bc
D	(12.00 pm - 02.00 pm)	0.9bc
E	(02.00 pm - 04.00 pm)	1.7abc
F	(04.00 pm - 06.00 pm)	0.8c

Standard error of mean = 0.30

Coefficient of variation = 20.93%

a,b,c means denoted by the same letter are not significantly different at the level of P = 0.05 (Duncan's (1955) New Multiple Range test).

mother aphid on Mwezi Moja variety was 55.2 nymphs and ranged between 46 and 65 nymphs, whereas the mean number of offsprings of the aphids produced on Red Haricot variety was 56.2 nymps and ranged between 48 and 62 nymphs. There was greater variation in the number of progeny produced by A. fabae on Mwezi Moja variety (SD = 7.19 nymphs) than on Red Haricot variety (SD = 5.45 nymphs) (Table 3). The difference in the mean number of progenies of aphids produced on the two varieties (1.0 nymph) was therefore minor as compared to the difference in the number of nymphs produced by the aphids on plants of the same bean variety. This indicated that the variation in total number of progeny produced by A. fabae on Red Haricot and Mwezi Moja varieties was not due to varietal differences but was apparently due to differences in the aphids themselves.

It was shown by these results (Table 3) that a large number of progeny of upto 65 nymphs was produced by each mother aphid during a mean reproduction period of 15 3 days. Considering that A. fabae development on beans was found to take 7.8 days, the short duration of nymphal development and

Table 3: The production of progenies by the bean aphid A. fabae during the reproductive life of mother aphids on common beans P. vulgaris.

bean varieties	number of progeny per mother aphid		
	mean	range	SD
Mwezi Moja (GLP. 10)	55.2	46-65	7.19
Red Haricot (GLP. 3)	56.2	48-62	5.45
duration of larviposition	15.3 days	11-17 days	1.59 days

SD = standard deviation

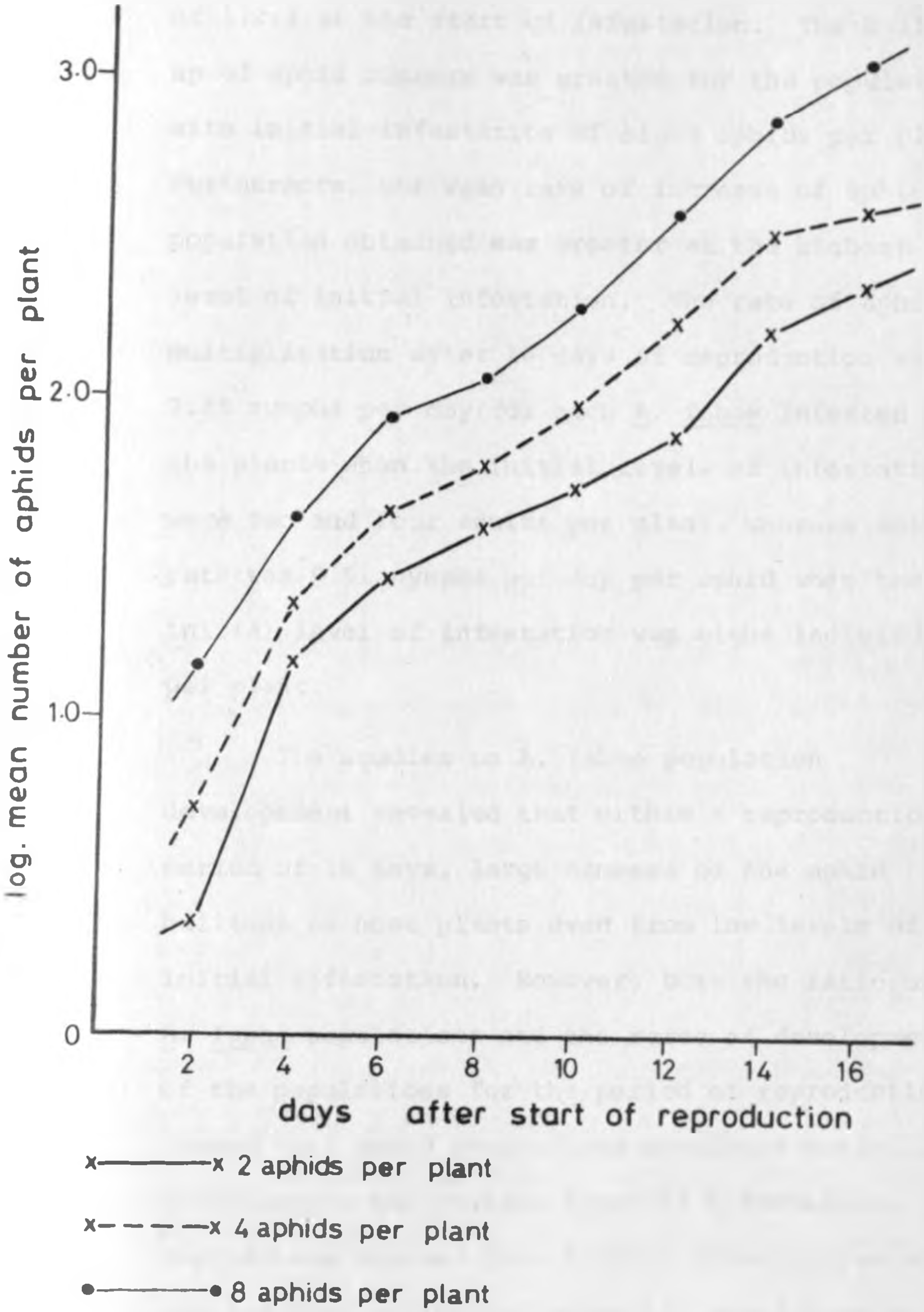
the large number of progeny produced by each mother aphid during a short period of larviposition would imply that an extremely rapid rate of increase of the pest could be realised when the aphids fed on common beans.

3:3:4 The population development of the bean aphid *A. fabae* on common beans *P. vulgaris* under greenhouse conditions.

The development of *A. fabae* populations on seedlings of common beans when aphids infested to them at the levels of two, four and eight adults per plant were left to reproduce for 16 days is presented in Figure 1. The build-up of the aphids on beans showed common pattern in having two peaks of development between one to eight days and eight to sixteen days from the start of reproduction, regardless of their initial levels of infestation (Fig. 1).

After 16 days of reproduction, the mean number of aphids on seedlings of beans that were initially infested with two, four and eight mature *A. fabae* per plant was 238.5, 486.2, and 1217.5 nymphs respectively. The ratio of mean number of nymphs

Fig.1. The build-up of A. fabae populations on the bean variety Red Haricot, from three initial levels of aphid infestation.



per plant was 1:2:5 as compared to the ratio of 1:2:4 at the start of infestation. The build-up of aphid numbers was greater for the population with initial infestation of eight aphids per plant. Furthermore, the mean rate of increase of aphid population obtained was greater at the highest level of initial infestation. The rate of aphid multiplication after 16 days of reproduction was 7.45 nymphs per day for each A. fabae infested to the plants when the initial levels of infestation were two and four adults per plant, whereas this rate was 9.51 nymphs per day per aphid when the initial level of infestation was eight individuals per plant.

The studies on A. fabae population developement revealed that within a reproduction period of 16 days, large numbers of the aphid built-up on host plants even from low levels of initial infestation. However, both the ratio of A. fabae populations and the rates of development of the populations for the period of reproduction showed that aphid populations developed unequally depending on the initial level of infestation. Populations derived from initial infestations of two and four aphids per plant had similar rates for each aphid infested, while the rate was higher for infestation of eight aphids per plant. The results further indicated that two generations of the aphids developed on the plants during this period of reproduction, reflecting closely earlier observations on the duration of the "developmental period" of the aphids which was 7.8 days. These studies therefore indicated that even small infestations of A. fabae have the potential to multiply and cause serious damage to host plants, and that rapid and more severe damage could result from higher levels of initial infestation.

3:4 DISCUSSION

The importance of aphid biological study in the evaluation of the relationship between aphid pests and their host plants has been emphasised (van Emden, 1972; Bond and Lowe, 1975). Observations in the current studies showed that when A. fabae fed on common beans developed into winged adults the nymphs took longer to develop (mean 9.5 days) than when they developed into wingless adults (mean 7.8 days). The reason for this difference was not immediately known, but perhaps the development of winged forms required more time to complete than was necessary for the development of wingless adults. Nevertheless the overall mean development period was very short; this being typical for aphids (Kennedy and Stroyan, 1959; Davidson and Fisher, 1922).

It has been observed in previous studies that the duration of *A. fabae* development on a given host plant decreased with increased temperature (Davidson, 1925). It was however not known whether the shorter duration of development obtained in this study wa due to the high temperatures (mean 26.5°C) that prevailed, as this parameter was not tested.

Observations in the present studies also showed that nymphal production during the day was characterised by fluctuations with a high rate of larviposition during the morning periods. Similar fluctuations have been reported for the moulting and flight rhythms of *A. fabae* (Eastop, 1957; Johnson *et. al.*, 1957a, b). These workers considered that the higher biological activity of *A. fabae* observed in the morning was most likely due to a slowing down of the development process during the night because of lower temperatures and reduced levels of plant assimilates, with the development process being accomplished rapidly in the mornings. It is most likely that the high rate of larviposition which occurred in the mornings during the current studies was governed by the same factors.

Data obtained also showed that A. fabae had a high rate of population build-up, with the rates being higher the higher the initial level of aphid infestations. These results were in conformity with previous observations on A. fabae population development (Davidson, 1925; Kennedy and Stroyan, 1959; Barlow, 1973).

It would appear from these investigations that because of the short duration of nymphal development and the high rate of larviposition, even very low infestation of A. fabae on common beans could develop to harmful proportions over a short period of time given favourable environmental conditions. A. fabae is thus potentially a very serious pest of beans and could cause considerable problems to common bean production if left uncontrolled.

CHAPTER 4

THE INFLUENCE OF THE LEVEL OF A. FABAE INFESTATION, VIRUS INFECTION, SOIL MOISTURE AND FERTILITY AND THE STAGE OF DEVELOPMENT AT WHICH THE APHIDS ARE INFESTED TO THE PLANTS ON THE GROWTH, DEVELOPMENT AND YIELD OF COMMON BEANS (P. VULGARIS) UNDER GREENHOUSE CONDITIONS.

4:1 INTRODUCTION

The damage caused to bean crops by the bean aphid *A. fabae* may be influenced by several factors which include the level of aphid infestation or abundance, transmission of plant virus diseases, conditions of plant growth, and the stage of development at which the plants are attacked (Hill, 1975; Way *et. al.*, 1954; Wayhray and Singh, 1965). It has, for instance, been reported that different levels of aphid populations cause different amounts of damage to the host plants (Judenko *et. al.*, 1952; Singh and van Emden, 1979; Barlow, 1973).

An indirect damage to plants caused by aphid attack is the transmission of plant virus diseases. It is known that aphids sometimes do more damage by transmitting viruses than by removing plant sap

(Dixon, 1978). The effects of virus diseases transmitted to plants by the aphids depend on the stage of growth at which the aphids attack the plants (Smith, 1972). Thus, it is known that for most bean infections that occur after flowering, Common Bean Mosaic Virus (CBMV) transmitted by aphids does not reach the seeds (Nelson, cited by Smith, 1972).

It is also known that the conditions of growth of the plants at the time of insect attack may influence the relative severity of attack and hence the ultimate degree of damage caused to plants (Davidson, 1925; Wayhray and Singh, 1965 Kennedy, 1958). Regarding the stage of growth and development at which aphids infest the crops, it has been observed that field beans, V. faba attacked by A. fabae in their early preflowering stages suffered more damage than those that were attacked later (Way et. al., 1954).

Much of the information relating to aphid attack, and the factors which influence the degree of damage caused by the bean aphid A. fabae to common beans P. vulgaris in Kenya is lacking. Reported here are therefore several experiments which were conducted to obtain this vital information

4:2 MATERIALS AND METHODS

4:2:1 The influence of two levels of *A. fabae* infestation and the stage of development at which the aphids are infested to the plants on the development and yield of common beans *P. vulgaris*.

The studies reported in this section were carried out to evaluate the effects on the performance of beans of *A. fabae* infested to the plants at two levels of populations during four stages of growth and development. Damage to bean growth, development and yield from aphid infestations under these conditions were therefore assessed.

The experiments were conducted at the University Farm, Field Station, Kabete Campus during 1982. Bean seedlings of the variety Mwezi Moja (GLP. 10) grown in soil consisting of a mixture of forest soil and farm-yard manure in 48 pots (top diameter 30 cm) were thinned to two per pot one week after emergence. Freshly moulted *A. fabae* adults were infested to the plants at two contrasting levels of six and three aphids per plant. The infestations were carried out at four stages of bean development, adopted for the purpose of these studies from a previous description (Anon. 1974 c) as follows:-

(i) early vegetative stage (EV) (one to two weeks after emergence). This is a period of slow growth and small plant volume. Plants were infested with aphids one week after emergence.

(ii) late vegetative stage (LV) (two to four weeks after emergence). This is a period of rapid growth and greatly increased plant volume. Plants were infested with aphids three weeks after emergence.

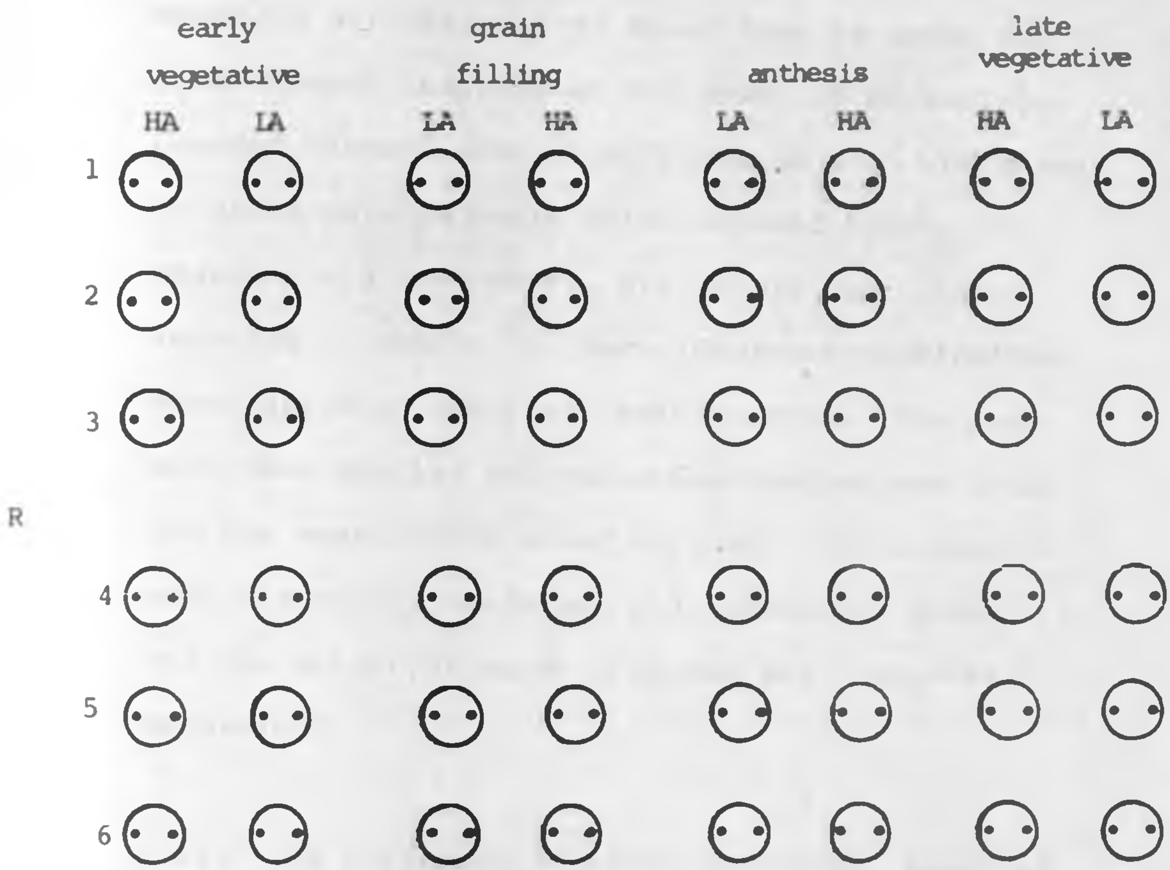
(iii) anthesis stage (A) (four to seven weeks after emergence). This is a period of limited reproductive growth and extensive flowering. Plants were infested with the aphids five weeks after emergence.

(iv) grain filling stage (GF) (from seven weeks to plant maturation). This is a period of reduced flowering, pod formation and extensive seed development with little plant growth. Plants were infested with the aphids seven weeks after emergence. Infestation at this stage was taken as the control.

This was therefore a two by four factorial experiment, replicated six times. The lay-out of the experiment in the greenhouse was as shown in Figure 2. The pots were separated from each other by 0.5 m corridors. The various treatments were assigned to the groups of plants at random.

The effects of *A. fabae* infestation on plant growth was measured in two ways. First the growth of central shoots was measured, and secondly the growth of (axillary) vegetative tillers and reproductive shoots was also measured. The height of central shoot was taken as the length of the shoot from the base of the stem above the surface of the soil to the tip of the bud of the shoot. Whereas the length of axillary shoot was taken as the length of the shoot from the axil to the tip of the bud of the shoot. The growth of central and axillary shoots was measured at intervals of two weeks for ten weeks starting one week after

Figure 2: The layout in the greenhouse of the experiment on the influence of two levels of A. fabae infestation and the stage of development at which the aphids are infested to the plants on the development and yield of common beans P. vulgaris.



= Plastic pots top diameter 30 cm.

• • = Bean plants, two per pot.

LA = plants infested with three pahids each

HA = plants infested with six aphids each.

R = replicates (1-6).

emergence.

To assess flower production by bean plants, one plant from each pot was selected at random and examined at intervals of three days to count fully open flowers starting at the onset of flowering. Counted flowers were clearly marked with black ink on the sepals to avoid being counted again. To assess yield components, six mature bean plants selected at random for each treatment combination were harvested and their pods counted. The pods were then shelled and the seeds counted and dried for one week before being weighed. The number of pods per plant, seeds per pod, seeds per plant, and the weight of seeds produced per plant was determined.

4:2:2 The influence of virus infection, level of *A. fabae* infestation and the stage of development at which the aphids were infested to the plants on the growth and yield of common beans *P. vulgaris*.

The studies reported here were conducted so as to assess the nature and magnitude of damage caused to beans when they were infested with virus free and virus-carrying *A. fabae* individuals at two levels of infestation during four stages of plant growth and development. The effects of the Common Bean Mosaic Virus (CBMV) transmitted to the plants were also assessed. These studies were thus aimed at evaluating the relationship between plant damage caused by aphid attack, abundance of the pest, CBMV transmitted by the insects, and the stage of bean growth and development at which aphid infestation occurred on the plants.

The experiments were conducted at the Field Station during 1981 and 1982. Bean seedlings of the variety Mwezi Moja (GLP. 10) raised in pots (diameter 30 cm) were thinned to two plants per pot one week after emergence. The establishment of aphid transmission of CBMV on bean plants was based on the principles and techniques elucidated by Watson (1936, 1938). However, because of the large number of aphids required for these experiments, and the excessive loss of insect material that it entailed, transfer of virus free aphids from healthy plants on which they were reared, onto diseased plants infected with CBMV, then to the experimental plants was found impracticable. A simpler and yet effective method was therefore adopted whereby aphids carrying CBM Virus were reared directly on diseased bean seedlings which were previously infected with the virus mechanically, while virus free aphids were reared on healthy virus-free plants as described in earlier studies in Chapter 3.

A. fabae were infested to bean plants at the level of six and three aphids per plant. From the two source colonies, two types of aphids were obtained and used to infest the plants, namely:-

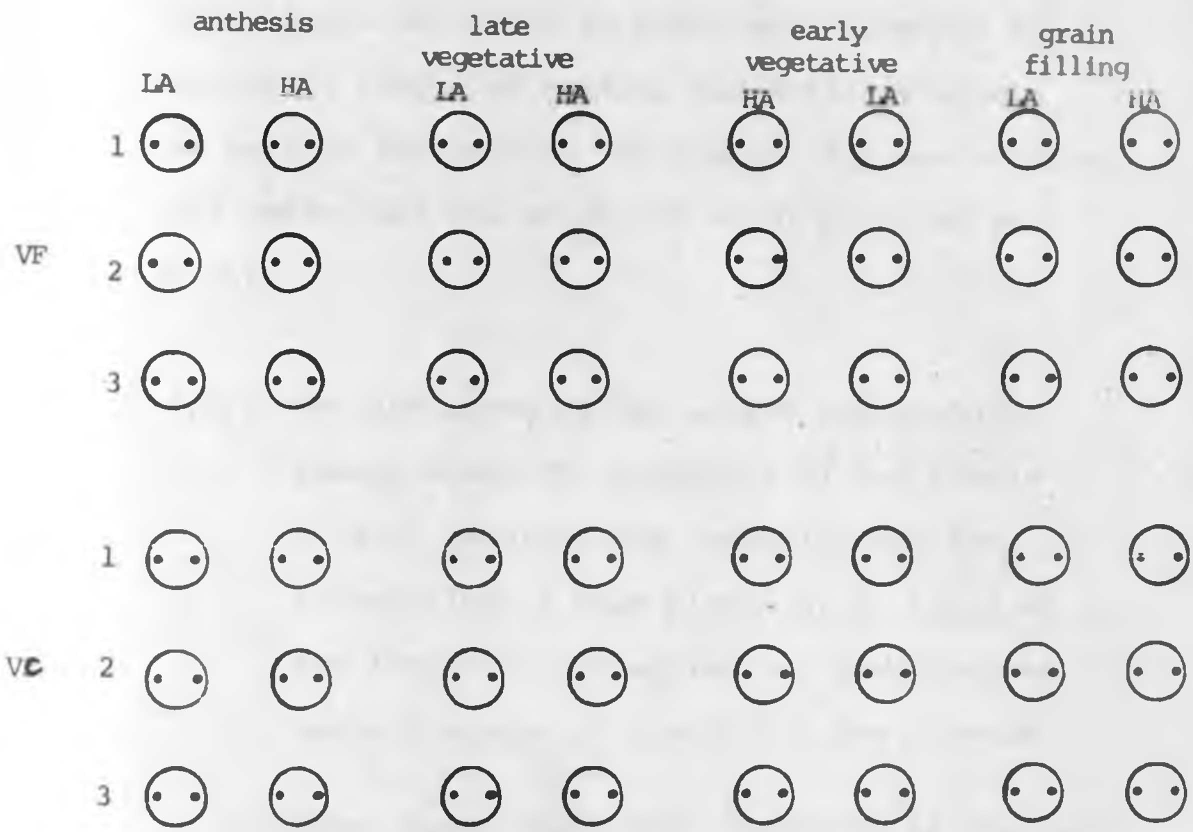
(i) healthy, virus-free aphids

(ii) aphids carrying CBM virus that were therefore capable of transmitting the disease.

The aphids were starved for about 30 minutes after dislodging from bean hosts before being infested to the experimental plants. They were infested to the plants at the four stages of development, namely early vegetative (EV), late vegetative (LV), anthesis (A) and grain filling (GF) as described in the previous studies.

This two by two by four factorial experiment was laid-out in the greenhouse as shown in Figure 3. The pots were separated from each other by 0.5 m

Figure 3: The lay-out in the greenhouse of the experiment on the influence of virus infection, level of A. fabae infestation and the stage of development at which the aphids are infested to the plants on the growth and yield of common beans P. vulgaris.



= Plastic pots top diameter 30 cm

• • = Bean plants, two per pot.

LA = plants infested with three aphids each
HA = plants infested with six aphids each
VC = plants infested with virus-carrying aphids.
VF = plants infested with virus-free aphids.

corridors and the various treatments were assigned to the groups of plants at random. The performance of beans was evaluated using six replicate plants for each treatment combination. The growth, development and yield of beans were assessed by measuring length of central and axillary shoots, as well as determining the number of flowers, pods, and seeds, and the weight of seeds produced per plant.

4:2:3 The influence on the growth and yield of common beans (P. vulgaris) of two levels of soil moisture and fertility and the infestation of bean plants by A. fabae at the level of four aphids per plant during various stages of growth and development.

These experiments were conducted to evaluate in the greenhouse the effects on the performance of beans of the conditions of plant growth and development and the infestation of beans by A. fabae at four stages of development. These studies were also conducted at the University Farm during 1982. Beans of the variety Red Haricot (GLP. 3), characterised by extensive growth of central shoots, were used in these experiments. The seedlings were grown in pots (diameter 30 cm) and thinned to two plants per pot one week after emergence. The plants were grown in soil consisting of an equal mixture by volume of brown sand, and exhausted soil previously used to grow bean plants in these studies. The potting soil was thus low in plant nutrients.

In order to maintain two contrasting levels of soil fertility, bean plants were grown in two types of soil as follows:

(i) Soil of low nutrient level: This consisted of the potting soil without any addition of fertilizer.

(ii) Soil of high nutrient level: This consisted of the potting soil to which was added 10.0 g of diammonium phosphate (DAP) fertilizer per pot.

The plants were watered so as to maintain a contrasting low and high levels of soil moisture. 0.5 and 2.0 litres of water per pot were supplied to plants each week. The bean plants were each infested with four freshly moulted A. fabae adults at the four stages of development, namely, early vegetative (EV), late vegetative (LV), anthesis (A) and grain filling (GF).

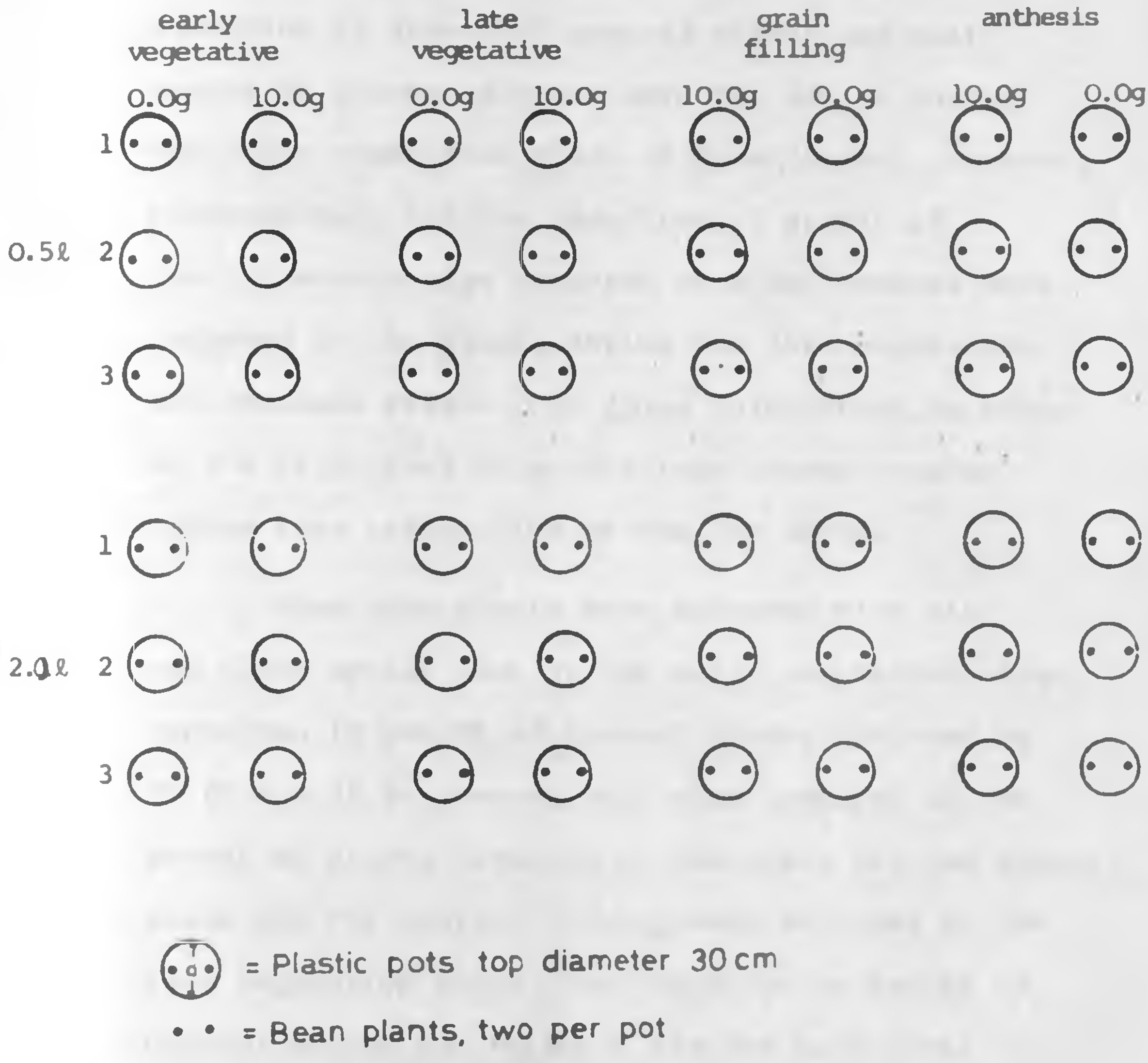
This was a two by two by four factorial experiment, laid-out in the greenhouse as shown in Figure 4. The pots were separated from each other by 0.5 m corridors, and the various treatments were assigned to the groups of plants at random. Using six replicate plants for each treatment combination, the performance of bean plants was assessed as described in previous experiments. The length of central shoots was measured, and the number of flowers, pods and seeds, and the weight of seeds produced per plant were also determined.

4:3 RESULTS.

4:3:1 The influence of two levels of *A. fabae* infestation and the stage of development at which the aphids were infested to the plants on the development and yield of common beans *P. vulgaris*.

The overall effects of damage caused to

Figure 4: The lay-out in the greenhouse of the experiment on the influence on the growth and yield of common beans (P. vulgaris) of two levels of soil moisture and fertility and the infestation of bean plants with A. fabae at the level of four aphids per plant during various stages of growth and development.



0.0g = plants grown without fertilizer.
10.0g= plants grown using 10.0g DAP per pot.
0.5ℓ= plants received 0.5ℓ of water/pot/week.
2.0ℓ= plants received 2.0ℓ of water/pot/week.

beans in terms of the growth of central shoots when A. fabae was infested to them at the levels of six and three aphids per plant are shown in Table 4. These results presented in Table 4 showed that the reduction in growth of central shoots was most severe on plants infested with the aphids during the early vegetative stage of development. However, progressively smaller reduction of growth of central shoots also occurred when the insects were infested to the plants during the late vegetative and anthesis stages. A. fabae infestation on beans at the high level of populations caused greater damage than infestation at the low level.

When bean plants were infested with six and three aphids each at the early vegetative stage, reduction in growth of central shoots occurred by 39.8% and 28.8% respectively when compared to the growth of plants infested at the grain filling stage, which was the control. For plants attacked at the late vegetative stage, the reduction in height of central shoots was by 10.6% for the high level of aphid infestation, and 2.3% for the low level as compared to the control. The corresponding reduction in growth when aphids were introduced onto beans at the anthesis stage was by 4.1% for plants infested with six aphids each and 3.6% for those infested with three aphids each.

The analysis of variance (Table 4) showed that the growth of central shoots of beans was significantly ($P = 0.05$) influenced by the level of A. fabae infested to the plants. The analysis further showed a highly significant ($P = 0.01$) linear and quadratic effects on the growth of central shoots for the stage of growth at which the aphids were infested to the plants (Table 4).

The linear component is the proportion of the sum of squares attributable to the linear regression of plant response on the stage of bean development at which A. fabae infestation occurred, while the quadratic component desribes a lack of fit to the linear response (Steel and Torrie 1980). In the present studies the linear components described bean responses to aphid attack during the vegetative and early anthesis stages of bean development when plant growth and development was rapid and increasing. The quadratic components described the non-linear plant responses to aphid infestation during and after the anthesis stage when the decrease in plant response became less for each delay in A. fabae attack.

Although the cubic effect of the stage of bean development on the growth of central shoots was highly significant at $P = 0.01$ (Table 4), its sum of squares was only 4.9% of the total sum of squares due to the stage of development during which the aphids were infested to the plants. Since the cubic response can be considered as a deviation from, or a lack of fit to the quadratic response (Steel and Torrie, 1980), the small proportion of the sum of squares attributable to it indicated that the relationship between bean response (in this case growth) and the time of A. fabae infestation consisted essentially of a linear and quadratic components. Furthermore the data on the growth of central shoots did not show a cubic trend (Table 4).

Comparison of the effects of A. fabae infestation at the two levels of aphid populations showed that aphids infested to beans at the level of six individuals per plant caused significantly ($P = 0.01$) greater reduction in growth of central shoots than those infested at the level of three individuals per plant when infestation was effected at the early vegetative stage. However, when the insects were infested to beans during the late vegetative, anthesis and grain filling stages of development, the effects of the two levels of aphid populations were not significantly different at $P = 0.05$ (Table 4).

Examination of the effects of the stages of development during which the aphids were infested to the plants revealed that A. fabae infested to beans at the level of six aphids per plant caused significantly ($P = 0.01$) greater reduction in the growth of central shoots when the plants were infested at the early vegetative stage as compared to infestation at the late vegetative, anthesis and grain filling stages (Table 4). At this infestation level too, the growth of central shoots of beans attacked at the late vegetative stage was significantly (P = 0.01) smaller than for the grain filling control. However, the mean height of central shoots of beans infested at the anthesis stage was not significantly different from those infested with the aphids during the late vegetative and grain filling stages at the level of P = 0.05 (Table 4). When the plants were infested with three aphids each, the mean height of plants attacked at the early vegetative stage was significantly (P = 0.01) smaller than that of plants attacked by the pest at the late vegetative, anthesis and grain filling stages. There was no significant difference in the height of central shoots of plants infested with three aphids each during the late vegetative, anthesis and grain filling stages at P = 0.05 (Table 4).

The results presented in Table 4 indicated that bean plants attacked by *A. fabae* at the early and late vegetative stages of development suffered the greatest damage to growth of central shoots. It was also shown that the

Table 4: The means and analysis of variance of the height (cm) of central shoots of common beans infested at two levels of A. fabae populations during four stages of plant development.

a) analysis of variance of height (cm) of central shoots.

source of variation	df	SS	MS	F
total	47	4322.979		
stage of development (S)	(3)	3234.896		
linear	1	2438.438	2438.438	118.11**
quadratic	1	638.021	638.021	30.90**
cubic	1	158.437	158.437	7.67**
level of infestation (L)	1	123.521	123.521	5.98*
interaction S x L	3	138.729	46.243	2.24
error	40	825.833	20.646	

significant * at P = 0.05; ** at P = 0.01; CV = 8.55%
SE level mean = 0.927 cm; SE stage mean = 1.312 cm

b) mean height (cm) of central shoots of bean plants.

number of aphids/plant	stages of bean development			
	early vegetative	late vegetative	anthesis	grain filling
6 (high)	35.11[a]	55.50[b]	57.33[bc]	59.83[c]
3 (low)	43.00[a]	57.53[b]	58.51[b]	59.67[b]

LSD between level means 0.05 = 2.65 cm
0.01 = 3.55 cm

a,b,c: at each level of aphid infestation, means denoted by the same letter are not significantly different at P = 0.05 (Duncan's (1955) New Multiple Range test.

level of aphid populations was important when the aphids were infested to the plants during the early vegetative and late vegetative stages, with greater damage resulting from the higher level of infestation.

The effects on the growth of axillary shoots when bean plants were infested with A. *fabae* at two levels of populations during four stages of plant development is given in Table 5. These results (Table 5) showed that aphids infested to plants during their early vegetative stage caused tremendous suppression of the growth of axillary shoots. Large reduction in growth of the vegetative tillers and reproductive shoots also occurred on plants attacked by the pest during the late vegetative stage, while the aphids infested to beans at the anthesis stage also caused smaller, but substantial damage to the axillary shoots. Differences in the effects of the level of infestation was pronounced on plants attacked by aphids at the early vegetative and late vegetative stages, with the infestation of six aphids per plant being more damaging than that of three aphids per plant.

Bean plants infested with six and three aphids per plant at the early vegetative stage suffered a reduction in growth of axillary shoots by 89.1% and 71.8% respectively when compared to plants attacked at the grain filling stage. When the plants were infested at the late vegetative stage, the reduction in growth of vegetative tillers and reproductive shoots was by 27.0% for the high level of infestation and 25.3% for the low level when compared to the grain filling control. For plants attacked by aphids at anthesis stage, the corresponding reduction in growth of axillary shoots was by 6.7% and 3.1% for the infestation level of six and three aphids per plant respectively.

The analysis of variance (Table 5) revealed that the growth of axillary shoots was significantly (P = 0.01) influenced by the level of A. fabae infested to the plants. It also showed that the linear and quadratic effects for the stage of plant development at which the insects were infested to the plants on the growth of axillary shoots was highly significant at P = 0.01, while the cubic effect of stage of plant development was not significant at P = 0.05. Furthermore, the growth of axillary shoots was shown to be significantly (P = 0.05) influenced by the effects of the interaction between the level of aphid infestation and the stage of plant development at which the aphids were introduced onto the plants (Table 5).

The mean growth of axillary shoots of plants infested with six _A. fabae_ each were significantly (P = 0.01) smaller than those of plants infested with three aphids each when the aphids were infested to them at the early vegetative and late vegetative stages of development. For infestation that occurred during the anthesis and grain filling stages, the effects of the two levels of aphid populations on the growth of axillary shoots was not significantly different at P = 0.05 (Table 5). For both levels of aphid infestation, the growth of axillary shoots of plants attacked by _A. fabae_ at the early vegetative and late vegetative stages were significantly (P = 0.05) different from each other and from those of plants attacked by the aphids at the anthesis and grain filling stages. At the infestation level of six and three aphids per plant, the growth of axillary shoots of plants attacked at anthesis and grain filling stages were however not significantly different at P = 0.05

(Table 5).

The results presented in Table 5 indicated that the damage to axillary shoots occurred when aphids were infested to the plants during the two vegetative stages and at the anthesis stage of bean development. It was also indicated that damage to axillary shoot growth of beans from aphid attack that occurred during the pre-flowering stages of development was strongly influenced by the level of aphid populations.

Damage to bean plants in terms of the mean number of flowers produced when A. fabae was infested to them at the level of six and three aphids each during different stages of bean development is shown in Table 6. These results given in Table 6 showed that flowering was severely reduced on plants attacked by the pest at the early vegetative stage. Large reduction in flowering also occured on plants infested with the aphids at the late vegetative stage. However, only marginal reduction in flower production occurred on plants attacked by aphids at the anthesis stage. Flowering was comparatively similar for all plants infested with aphids at the two levels of

Table 5: The means and analysis of variance of the length (cm) of axillary shoots of common beans infested at two levels of _A. fabae_ populations during four stages of plant development.

a) analysis of variance of length (cm) of axillary shoots.

source of variation	df	SS	MS	F
total	47	109266.98		
stage of development (S)	(3)	100826.06		
linear	1	85390.54	85390.54	621.29**
quadratic	1	15087.52	15087.52	109 78**
cubic	1	348.00	348.00	2.53
level of infestation (L)	1	1463.02	1463.02	10.65**
interaction S x L	3	1580.40	526.80	3.83*
error	40	5497.50	137.44	

significant * at P = 0.05; ** at P = 0.01 CV = 11.27%
SE stage mean = = 3.384 cm SE level mean = 2.393 cm

b) mean length (cm) of axillary shoots of bean plants.

number of aphids/plant	stages of bean development			
	early vegetative	late vegetative	anthesis	grain filling
6 (high)	13.33[a]	102.50[b]	136.83[c]	141.33[c]
3 (low)	43.67[a]	112.50[b]	137.17[c]	146.83[c]

LSD between level means 0.05 = 6.84 cm
0.01 = 9.15 cm

a,b,c: for each level of aphid infestation, means denoted by the same letter are not significantly different at P = 0.05 (Duncan's (1955) New Multiple Range test).

populations (Table 6).

Plants infested with six and three aphids each at the early vegetative stage produced 85.1% and 77.4% fewer flowers respectively when compared to plants attacked at the grain filling stage. Infestation of the plants with A. fabae at the late vegetative stage resulted in the reduction in flowering by 42.8% for the high level of infestation and 37.5% for the low level of populations when compared to the control. For plants infested with six and three aphids each at the antnesis stage of development, the corresponding reduction in flowering was by 5.8% and 3.6% respectively.

The analysis of variance (Table 6) showed a highly significant (P = 0.01) linear and quadratic effects on flowering, for the stages of development during which the aphids were infested to the plants. The cubic effect for the stage of development was however not significant at P = 0.05. The analysis further showed that the influence of the level of aphid infestation and of the interaction between the level of infestation and the stage of development at which the aphids were infested to the plants on the number of flowers produced per plant was not significant at P = 0.05 (Table 6). When the plants were infested with A. *fabae* at the two levels of populations, the number of flowers produced by plants infested at the early vegetative and late vegetative stages were significantly (P = 0.01) different from each other and from those produced by plants attacked by the aphids at the anthesis and grain filling stages. Infestation at the anthesis stage did not cause significant reduction in the flowering of plants when compared to the control at P = 0.05 (Table 6).

The observations on the flowering of beans as presented in Table 6 indicated that plants attacked during their pre-flowering stages of development suffered severe reductions in flowering. The results also indicated that difference in the level of aphid populations did not markedly influence flowering in beans.

The effects on the number of pods produced per plant when bean plants were infested with A. *fabae* at the two levels of populations during four stages of development is shown in Table 7. These results (Table 7) showed that the number of pods produced per plant was severely reduced on

Table 6: The means and analysis of variance of the number of flowers produced per plant when common beans were infested at two levels of A. fabae populations during four stages of plant development.

a) analysis of variance of the number of flowers per plant.

source of variation	df	SS	MS	F
total	47	25280.98		
stage of development (S)	(3)	24386.23		
linear	1	21600.22	21600.22	1004.19**
quadratic	1	2762.58	2762.58	128.43**
cubic	1	23.43	23.43	1.09
level of infestation (L)	1	15.19	15.19	0.71
interaction S x L	3	19.06	6.35	0.30
error	40	860.50	21.51	

**significant at P = 0.01 CV = 9.46%

SE stage mean = 1.339 SE level mean = 0.947

b) mean number of flowers produced per plant

number of aphids/plant	stages of bean development: early vegetative	late vegetative	anthesis	grain filling
6 (high)	14.17[a]	41.17[b]	67.39[c]	71.23[c]
3 (low)	15.67[a]	44.00[b]	68.01[c]	70.87[c]

LSD between level means 0.05 = 2.71

0.01 = 3.62

a,b,c: at each level of aphid infestation, means denoted by the same letter are not significantly different at P = 0.05 (Duncan's (1955) New Multiple Range test).

beans attacked by the aphids during the early vegetative and late vegetative stages. Pod production was also reduced on plants infested with the pest at the anthesis stage. During these three stages, infestation of six aphids per plant was more damaging to the plants than that of three aphids per plant.

When compared to the grain filling control, the production of pods by plants infested with six and three aphids each at the early vegetative stage was reduced by 80.9% and 17.1% respectively. For plants attacked by _A. fabae_ at the late vegetative stage, the high and low levels of infestation resulted in the reduction in pod production by 53.0% and 16.4% respectively when compared to infestation at the grain filling control. The corresponding reduction in pod yield when aphids were infested to beans at the anthesis stage was 32.0% for six aphids per plant and 16.2% for three aphids per plant.

The analysis of variance (Table 7) showed that pod production by beans was significantly (P = 0.01) influenced by the level of _A. fabae_ infestation. The linear effects on pod yield for the stage of development at which the aphids were infested to the plants was also highly significant at P = 0.01. However, the quadratic and cubic effects of the stage of development and the effects of the interaction between the level of infestation and the stage of development at which the insects were infested to beans on the number of pods produced per plant were not significant at P = 0.05.

For plants attacked by *A. fabae* at the early vegetative and late vegetative stages of development, the reduction in the number of pods produced per plant was highly significant (P = 0.01) for plants infested with six aphids each as compared to those infested with three aphids each. This difference was also significant (P = 0.05) for infestation at anthesis stage, but was not significant for infestation at the grain filling stage at P = 0.05 (Table 7). When the plants were infested with six and three aphids each at the four stages of development, the number of pods produced per plant was significantly (P = 0.01) different for plants attacked at the early vegetative, late vegetative and anthesis stages when compared to each other and when compared to those attacked at the grain filling stage (Table 7).

These results presented in Table 7 indicated that at both levels of A. fabae infestation, severe reduction in pod yield occurred on plants attacked by aphids during the early vegetative, late vegetative and anthesis stages. The influence of level of aphid populations on pod production was important when aphids were infested to the plants during the pre-flowering stages of development.

The effects on the number of seeds produced per pod of the infestation of beans with A. fabae at two levels of populations during different stages of plant development is shown in Table 8. These results (Table 8) showed that substantial reduction in the number of seeds per pod occurred on plants attacked by the pest at the early vegetative stage. Progressively smaller reduction also occurred when aphids were infested to the plants at the late vegetative and anthesis stages of development. Higher levels of aphid populations generally resulted in greater effects on the number of seed per pod.

A. fabae infested to bean plants at the level

Table 7: The means and analysis of variance of the number of pods produced per plant when A. *fabae* were infested to common beans at two levels of populations during four stages of plant development.

a) analysis of variance of the number of pods per plant.

source of variation	df	SS	MS	F
total	47	335.48		
stage of development (S)	(3)	243.73		
linear	1	241.51	241.51	171.29**
quadratic	1	0.41	0.14	0.10
cubic	1	2.08	2.08	1.47
level of infestation (L)	1	17.52	17.52	14.88**
interaction S x L	3	17.73	5.91	5.02
error	40	56.50	1.41	

**significant at P = 0.01 CV = 18.57%

SE stage mean = 0.343 SE level mean = 0.242

b) mean number of pods produced per plant.

number of aphids/plant	stages of bean development: early vegetative	late vegetative	anthesis	grain filling
6 (high)	2.01[a]	4.67[b]	6.67[c]	9.83[d]
3 (low)	4.83[a]	6.33[b]	7.50[c]	9.33[d]

LSD between level means 0.05 = 0.69

0.01 = 0.93

a,b,c,d: at each level of aphid infestation, means denoted by the same letter are not significantly different at P = 0.05 (Duncan's (1955) New Multiple Range test).

of six and three aphids each caused reduction in the mean number of seeds per pod by 33.9% and 27.7% respectively when the plants were infested with the aphids at the early vegetative stage as compared to the grain filling stage. For plants attacked by the aphids at the late vegetative stage, the reduction in the mean number of seeds per pod were by 13.3% for plants infested with six aphids each and 9.7% for those infested with three aphids each when compared to the control. The corresponding reduction in mean number of seeds per pod when the aphids were infested to beans at the anthesis stage were 6.3% and 3.7% for high and low levels of aphid infestation respectively.

The analysis of variance (Table 8) showed a highly significant (P = 0.01) linear effect on the number of seeds per pod for the stage of development at which the aphids were infested to the plants. The quadratic and cubic effects for the stage of bean development were not significant at P = 0.05. The analysis further showed that the effects on the number of seeds per pod of the level of _A. fabae_ populations and the interaction between the level of infestation and stage of development at which the aphids were infested to beans were also not significant at P = 0.05.

When A. fabae were introduced onto plants at both levels of populations, the reduction in the mean number of seeds per pod was significantly (P = 0.01) greater on beans attacked at the early vegetative stage as compared to those attacked at the late vegetative, anthesis and grain filling stages. Plants infested with aphids at the late vegetative stage also produced pods that had significantly (P = 0.01) fewer number of seeds each than the control (Table 8). However, the mean number of seeds per pod for plants infested with A. fabae at the anthesis stage was not significantly different from those of plants attacked by aphids during late vegetative and grain filling stages at P = 0.05 (Table 8).

The frequency of pods bearing different numbers of seeds for bean plants infested with three aphids each at the four stages of development is presented in Figure 5. These results (Figure 5) showed that the proportion of pods possessing fewer than four seeds each was greater when plants were attacked by aphids at the early vegetative and

Table 8: The means and analysis of variance of the number of seeds per pod when A. fabae were infested to common beans at two levels of populations during four stages of plant development.

a) analysis of variance of the number of seeds per pod.

source of variation	df	SS	MS	F
total	47	15.819		
stage of development (S)	(3)	7.730		
linear	1	7.255	7 255	39.22**
quadratic	1	0.473	0.473	2.56
cubic	1	0.002	0.002	0.01
level of infestation (L)	3	0.435	0.435	2.36
interaction S x L	3	0.374	0.125	0.68
error	40	7.380	0.185	

**significant at P = 0.01 CV = 12.59%

SE stage mean = 0.124; SE level mean = 0.088

b) mean number of seeds produced per pod.

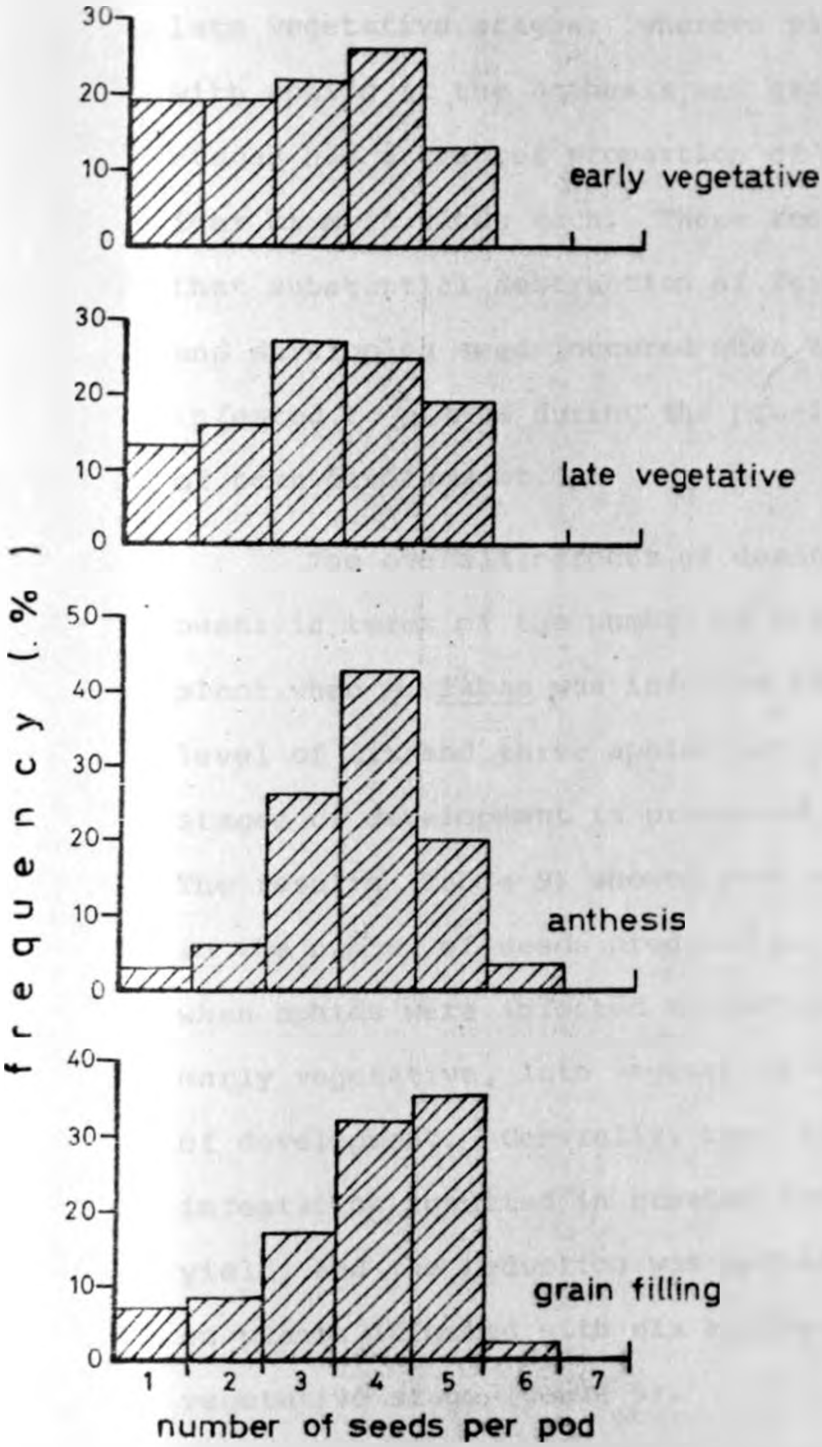
number of aphids/plant	stages of bean development			
	early vegetative	late vegetative	anthesis	grain filling
6 (high)	2.53[a]	3.32[b]	3.59[bc]	3.83[c]
3 (low)	3.01[a]	3.42[b]	3.70[bc]	3.84[c]

LSD between level means 0.05 = 0.25

0.01 = 0.34

a,b,c: at each level of aphid infestation, means denoted by the same letter are not significantly different at P = 0.05 (Duncan's (1955) New Multiple Range test).

Fig. 5. The frequency of pods bearing different number of seeds of Mwezi Moja bean plants infested with three aphids each at four stages of development.



late vegetative stages; whereas plants infested with aphids at the anthesis and grain filling stages had a greater proportion of pods bearing four or more seeds each. These results indicated that substantial destruction of fertilized ovules and developing seeds occured when aphids were infested to plants during the pre-flowering stages of bean development.

The overall effects of damage caused to beans in terms of the number of seeds produced per plant when *A. fabae* was infested to them at the level of six and three aphids per plant during four stages of development is presented in Table 9. The results (Table 9) showed that serious reduction in the number of seeds produced per plant occurred when aphids were infested to the plants at the early vegetative, late vegetative and anthesis stages of development. Generally, the higher level of aphid infestation resulted in greater reduction in seed yield, and the reduction was particularly severe on plants infested with six aphids each at the early vegetative stage (Table 9).

When the plants were attacked by *A. fabae* at the early vegetative stage, the number of seeds produced per plant was reduced by 86.8% for plants infested with six aphids each, and by 61.6% for those infested with three aphids each when compared to the control. For infestation that occurred at the late vegetative stage, the respective reduction in the number of seeds produced per plant for the high and low levels of aphid populations were by 59.0% and 42.6% as compared to the number of seeds of plants attacked by the pest at the grain filling stage. Plants infested with six and three aphids each at the anthesis stage produced 37.0% and 22.7% less seeds respectively when compared to control.

The analysis of variance (Table 9) showed that the number of seeds produced per plant was significantly (P = 0.05) influenced by the level of A. fabae populations infested to them. The linear effects on seed yield for the stage of bean development at which the aphids were infested to the plants was also highly significant at P = 0.01. The quadratic and cubic effects for the stage of development, and the effects of the interaction between the level of infestation and the stage of development at which the aphids were infested to the plants on the number of seeds produced per plant was not significant at $P = 0.05$.

For bean plants attacked by _A. fabae_ at the early vegetative and late vegetative stages of development the reduction in the number of seeds produced per plant was highly significant ($P = 0.01$) for plants infested with six aphids each as compared to those infested with three aphids each. This difference was also significant ($P = 0.05$) for infestation at the anthesis stage, but was not significant for infestation during the grain filling stage at $P = 0.05$ (Table 9). When the plants were infested with aphids at both levels of populations, the number of seeds produced per plant was significantly ($P = 0.01$) different for infestation at the early vegetative, late vegetative and anthesis stages when compared to each other and as compared to infestation at the grain filling stage.

The results presented in Table 9 indicated that serious reduction in seed yield occurred when aphids were infested to bean plants during the vegetative growth stages and at flowering. The results also indicated that damage caused to beans by aphids infested to them at these stages of

Table 9: The means and analysis of variance of the number of seeds produced per plant when A. *fabae* were infested to common beans of two levels of populations during four stages of plant development.

a) analysis of variance of the number of seeds per plant.

source of variation	df	SS	MS	F
total	47	6501.82		
stage of development (S)	(3)	4915.40		
linear	1	4876.58	4876.58	160.58**
quadratic	1	3.43	3.42	0.11
cubic	1	35.80	35.80	1.16
level of infestation (L)	1	196.62	196.62	6.48*
interaction S x L	3	175.63	58.54	1.93
error	40	1214.17	30.35	

significant * at $P = 0.05$; ** at $P = 0.01$; CV = 24.42%

SE stage mean = 1.590 SE level mean = 1.125

b) mean number of seeds produced per plant.

number of aphids/plant	stages of bean development			
	early vegetative	late vegetative	anthesis	grain filling
6 (high)	5.00[a]	15.50[b]	23.83[c]	37.83[d]
3 (low)	13.83[a]	20.67[b]	27.83[c]	36.09[d]

LSD between level means 0.05 = 3.22

0.01 = 4.30

a,b,c,d: at each level of aphid infestation, means denoted by the same letter are not significantly different at P = 0.05 (Duncan's (1955) New Multiple Range test).

development depended on the level of A. fabae populations.

The influence on the weight of seeds produced per plant when A. fabae were infested to beans at the two levels of populations during four stages of plant development is presented in Table 10. The results (Table 10) showed that aphids infested to the plants at the early vegetative, late vegetative and anthesis stages caused substantial reduction in the weight of seeds produced. For all these stages of development plants infested with six aphids each suffered greater damage to seed yield than those infested with three aphids each.

When A. fabae were introduced onto beans at the early vegetative stage, plants infested with six aphids each suffered reduction in the weight of seeds produced per plant by 84.2%, while those infested with three aphids each suffered reduction in seed yield by 62.9% as compared to the grain filling control. Infestation of six and three aphids per plant at the late vegetative stage resulted in the reduction in the weight of seeds produced per plant by 54.5% and 42.4% respectively as compared to the control. When aphid attack occured at the anthesis stage, the corresponding reduction in the weight of seeds produced per plant was by 46.3% for the infestation of six aphids per plant and 25.3% for infestation of three aphids per plant.

The analysis of variance (Table 10) showed that the weight of seeds produced per plant was significantly (P = 0.05) influenced by the level of aphid infestation. There was also a highly significant (P = 0.01) linear effect on seed yield for the stage of development at which the aphids were infested to the plants. The quadratic effect for the stage of plant development was not significant at P = 0.05. Although the cubic effect for the stage of development at which the aphids were infested to beans showed significance at P = 0.05, its sum of squares was however only 3.1% of the total sum of squares due to the stage of development and the results did not show a cubic trend (Table 10).

Comparison of the effects of A. fabae infestation at the level of six and three aphids per plant showed that aphids infested to beans at the higher level caused significantly (P = 0.01) greater reduction in the weight of seeds produced per plant than those infested at the lower level of populations when the infestations were effected at the early vegetative and late vegetative stages. This difference was also significant ($P = 0.05$) for infestation at the anthesis stage, but was not significant for the grain filling stage at $P = 0.05$ (Table 10). For plants infested with A. fabae at both levels of populations, the weight of seeds produced per plant was significantly ($P = 0.01$) different for infestation at the early vegetative, late vegetative and anthesis stages when compared to each other and when compared to the control.

The frequency of seeds of the various weight categories produced by bean plants infested with three aphids each at the four stages of development is shown in Figure 6. The results (Figure 6) showed that there was greater variation in the individual weight of seeds obtained from plants attacked by A. fabae during the early vegetative and late vegetative stages than was the case for plants attacked by the aphids at the anthesis and grain filling stages of development.

The result presented in Table 10 indicated that the reduction in the weight of seeds produced

Table 10: The means and analysis of variance of the weight (gm) of seeds produced per plant when *A. fabae* were infested to common beans at two levels of populations during four stages of plant development.

a) analysis of variance of the weight (gm) of seeds per plant.

source of variation	df	SS	MS	F
total	47	1828.50		
stage of development (S)	(3)	1435.86		
linear	1	1388.73	1388.73	182.73**
quadratic	1	2.92	2.92	0.38
cubic	1	44.21	44.21	5.90*
level of infestation (L)	1	44.87	44.87	5.90*
interaction S x L	3	43.67	14.56	1.91
error	40	304.10	7.60	

significant * at P = 0.05; ** at P = 0.01 CV = 19.81%

SE stage mean = 0.796 gm; SE level mean = 0.563 gm

b) mean weight (gm) of seeds produced per plant

number of aphids/plant	stages of bean development			
	early vegetative	late vegetative	anthesis	grain filling
6 (high)	3.68[a]	10.53[b]	15.41[c]	23.12[d]
3 (low)	8.47[a]	13.17[b]	17.10[c]	22.85[d]

LSD between level means 0.05 = 1.61 gm

0.01 = 2.15 gm

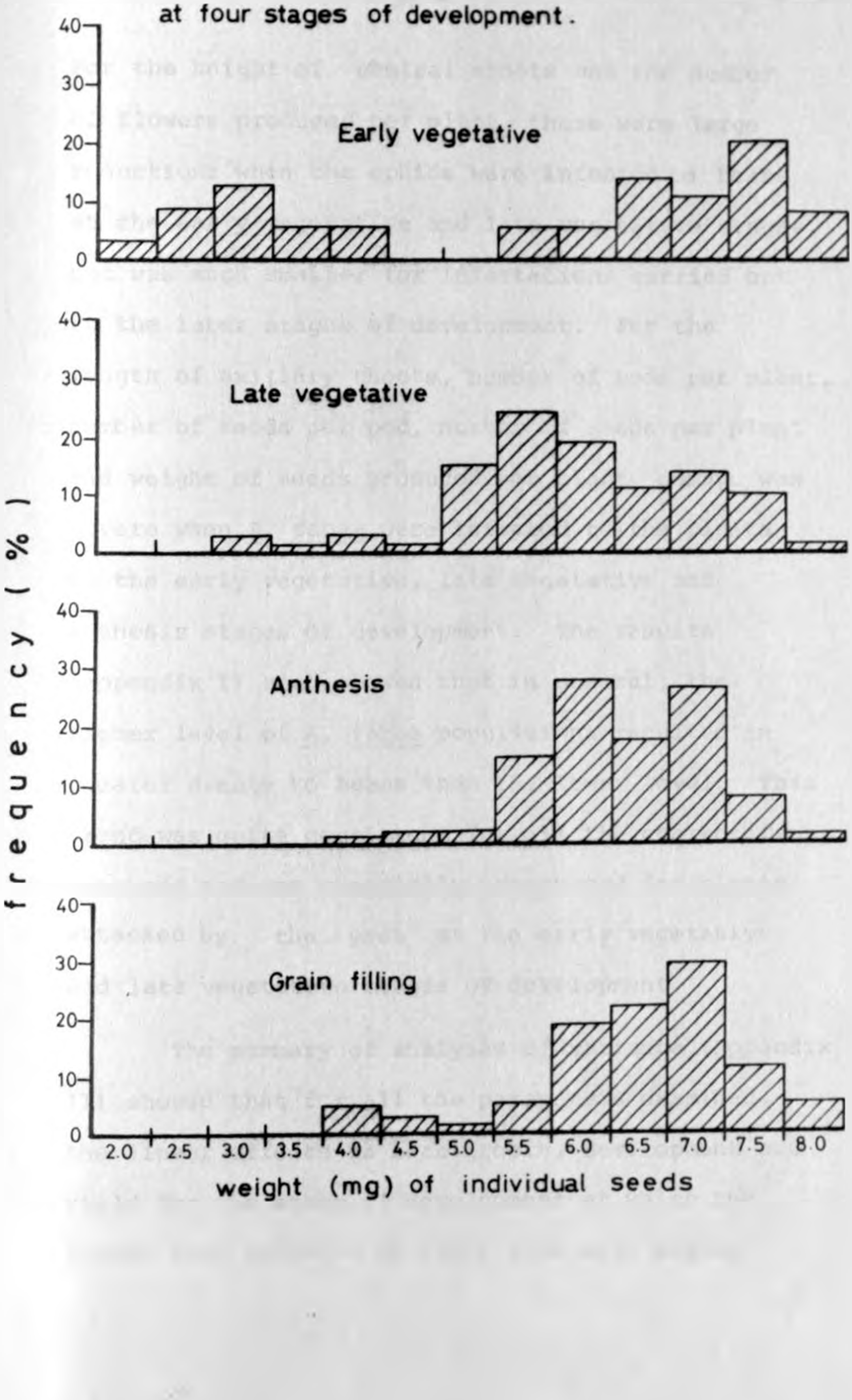
a,b,c,: at each level of aphid infestation, means denoted by the same letter are not significantly different at P = 0.05 (Duncan's (1955) New Multiple Range test).

per plant was severe for plants attacked by *A. fabae* at the pre-flowering and anthesis stages of development. It was also indicated that damage caused to beans differed with the level of aphid populations. Furthermore, the results presented in Figure 6 indicated that earlier aphid attack increased the variability of seeds.

A summary of the means for the various parameters of bean growth, reproduction and yield assessed when *A. fabae* were infested to the plant at the levels of six and three aphids each during the early vegetative, late vegetative, anthesis and grain filling stages of development is presented in Appendix Table I. A summary of the analyses of variance for these characters is also given in Appendix Table II.

The summary of means (Appendix I) showed that in general, *A. fabae* attack on beans during the early vegetative and late vegetative stages of development resulted in severe plant damage for all the characters measured. Smaller but substantial damage occurred when the plants were attacked by the aphids at the anthesis stage.

Fig.6. The frequency of seeds of various weight categories of Mwezi Moja bean plants infested with three aphids each at four stages of development.



For the height of central shoots and the number of flowers produced per plant, there were large reductions when the aphids were infested to beans at the early vegetative and late vegetative stages, but was much smaller for infestations carried out at the later stages of development. For the length of axillary shoots, number of pods per plant, number of seeds per pod, number of seeds per plant and weight of seeds produced per plant, damage was severe when A. fabae were infested to the plants at the early vegetative, late vegetative and anthesis stages of development. The results (Appendix I) also showed that in general, the higher level of A. fabae populations resulted in greater damage to beans than the lower level. This trend was quite consistent for all the characters measured and was especially pronounced for plants attacked by the pest at the early vegetative and late vegetative stages of development.

The summary of analyses of variance (Appendix II) showed that for all the parameters examined, the linear effects on bean growth, development and yield for the stage of development at which the aphids were infested to the plants were highly significant at P = 0.01. The quadratic effects for the stage of development on the height of central shoots, length of axillary shoots, and the number of flowers produced per plant were also highly significant at P = 0.01. Though the cubic effects for the stage of development on the height of central shoots and the weight of seeds produced per plant were also significant (P = 0.05), the results (Appendix I) did not show a cubic trend. The summary further showed that the effects of the level of A. fabae infestation was significant ($P \geq 0.05$) for all the characters measured, except the number of flowers per plant, and the number of seeds produced per pod. The only interaction effect that was significant (P = 0.05) was the influence on the length of the axillary shoots of the interaction between the level of A. fabae infestation and the stage of development at which the aphids were infested to the plants.

These results therefore indicated that the stage of bean development at which the aphids attacked the plants was the most important determinant of bean damage and aphid infestations during the pre-flowering stages were the most harmful. The level of A. fabae populations was also found to influence the damage caused to beans after aphid attack. This was particularly important when the plants were attacked by aphids at the early vegetative stage.

4:3:2 The influence of virus infection, level of A. fabae infestation, and the stage of development at which the aphids were infested to the plants on the growth and yield of common beans P. vulgaris.

The results of the growth of the central shoots of beans as influenced by the level of A. fabae infestation, bean infection by the Common Bean Mosaic Virus and the stage of development at which the aphids were infested to the plants is presented in Table 11. These results, Table 11, showed that plants attacked by aphids during the early vegetative and late vegetative stages of development suffered serious reduction in the growth of central shoots. A smaller reduction in growth also occurred on plants infested with the aphids at the anthesis stage. The reduction in growth was generally more severe on plants attacked by

A. fabae that carried and transmitted the Common Bean Mosaic virus than on beans infested with virus-free aphids. Furthermore, damage was more serious for plants infested with six aphids each than for those infested with three aphids each (Table 11).

The analysis of variance (Table 11) showed a highly significant (P = 0.01) linear and quadratic effects on shoot growth for the stage of development at which the aphids were infested to the plants. The cubic effect for the stage of development was not significant at P = 0.05. The sum of squares for the stage of development at which A. fabae were infested to beans was 85.6% of the treatment sum of squares. The analysis further showed that the effects of the level of aphid infestation, aphid virus status and of all the interactions between the three factors on the growth of the central shoots of beans were not significant at P = 0.05 (Table 11). The sums of squares for the level of aphid infestation, aphid virus status, and for all the interactions combined, were 1.8%, 5.3% and 7.3% respectively of the total sum of squares due to the treatments imposed on beans. This indicated that only a small proportion of the differences in bean growth due to all the treatments was attributable to the effects of level of aphid infestation, aphid virus status and all the interactions.

The comparison of means of the height of central shoots (Table 11) showed that when virus-free aphids were infested to beans at the level of six and three aphids per plant, plants attacked by the aphids at the early vegetative stage suffered significantly (P = 0.01) greater reduction in the growth of central shoots than those attacked by the pest at the late vegetative, anthesis and grain filling stages of development. However, the growth of central shoots of plants attacked by aphids at the late vegetative, anthesis and grain filling stages were not significantly different at P = 0.05. For bean plants infested with virus-carrying aphids at the level of six and three aphids each, infestation at the early vegetative and late vegetative stages resulted in significantly (P = 0.01) greater reduction in the growth of central shoots than infestation at the anthesis and grain filling stages of development. There was no significant difference in the growth of central shoots of plants attacked at the anthesis and grain filling stages at P = 0.05 (Table 11). However, when the population level was three aphids

Table 11. The means and analysis of variance of the height (cm) of central shoots of beans infected with virus free and virus carrying aphids at two levels of *A. fabae* populations during four stages of plant development.

a) analysis of variance of height (cm) of central shoots.

source of variation	df	ss	ms	F
total	95	33839.34		
stage of development (S)	(3)	10494.59		
linear	1	8738.13	8738.13	32.40**
quadratic	1	1650.04	1650.04	6.12**
cubic	1	106.42	106.42	0.39
virus status (V)	1	651.05	651.05	2.41
level of infestation (L)	1	216.01	216.01	0.80
interaction S x V	3	632.03	213.00	0.79
interaction S x L	3	253.41	84.47	0.31
interaction V x L	1	1.03	1.03	0.00
interaction V x L x S	3	18.55	6.18	0.02
error	80	21572.67	296.66	

**significant at P = 0.01 CV = 32.57%

SE stage means = 3.352 cm; SE (status or level) mean = 2.370 cm

b) mean height (cm) of central shoots of beans.

virus status of aphids	number of aphids/plant	stage of bean development			
		early vegetative	late vegetative	anthesis	grain filling
virus-free	6 (high)	35.03a	53.33b	57.54b	59.71b
	3 (low)	44.11a	55.35b	57.41b	59.69b
virus-carrying	6 (high)	24.24a	44.56b	56.99c	59.0[illegible]
	3 (low)	29.85a	50.72b	57.55b	59.1[illegible]

LSD between (status or level) means 0.05 = 6.70cm
0.01 = 8.92cm.

a,b,c: for each level of aphid infestation, means denoted by the [illegible] letter are not significantly (P = 0.05) different (Duncan's New per plant, only infestation at the early vegetative stage resulted in the growth of central shoots of beans being significantly (P = 0.01) different from that of the grain filling control.

The difference in growth of central shoots of plants infested with virus-free and virus-carrying A. fabae when the infestation level was six individuals per plant was significant (P = 0.01) for plants attacked at the early vegetative and late vegetative stages, but was not significant for plants attacked by the aphids during anthesis and grain filling stages at P = 0.05 (Table 11). When the aphids were infested to beans at the level of three individuals per plant, this difference was only significant (P = 0.01) for plants attacked at the early vegetative stage of development.

The results presented in Table 11 indicated that the stage of plant development at which A. fabae were infested to beans was the most important factor influencing bean damage by the aphids. It was also indicated by these results that the infection of beans with the Common Bean Mosaic virus resulted in greater retardation in growth of central shoots when plants were infected at the early vegetative, and late vegetative stages only. The level of aphid infestation was also shown to be important when *A. fabae* were infested to beans at the early vegetative and late vegetative stages of development only.

The overall effects of damage caused to beans in terms of the growth of axillary shoots when virus-free and virus-carrying *A. fabae* were infested to the plants at the level of six and three aphids each during four stages of development are shown in Table 12. The mean length of axillary shoots obtained (Table 12) showed that for plants infested with either virus-free or virus-carrying aphids, damage to the axillary shoots was most severe when the insects were infested to them at the early vegetative and late vegetative stages of development. Smaller but substantial damage also occurred on plants attacked by the pest at the anthesis stage. The reduction in the growth of the axillary shoots was most severe for plants infested with aphids that transmitted the Common Bean Mosaic virus. Greater reduction in the growth of axillary shoots also occurred on plants infested with six aphids each as compared to those infested with three aphids each

(Table 12).

The analysis of variance of the length of axillary shoots (Table 12) showed a highly significant (P = 0.01) linear and quadratic effects for the stage of development at which the aphids were infested to the plants. The cubic effect for the stage of development was however not significant at P = 0.05. The sum of squares for the stage of development was 94.2% of the total sum of squares due to the treatments imposed on the beans. The analysis further showed that the influence of the levels of A. fabae infestation, the virus status of the aphids, the effects of the interactions between the stage of bean development and virus status of the aphids, and the stage of development and level of aphid infestation on the growth of axillary shoots were highly significant at P = 0.01. However, these only accounted for 0.9%, 2.4%, 1.5% and 0.9% respectively of the total sum of squares due to the treatments imposed. The effect on the growth of axillary shoots of the interaction between all the three factors was not significant at P = 0.05 (Table 12).

When bean plants were infested with virus-free and virus-carrying aphids at the two levels of populations, the mean length of axillary shoots of plants attacked by the pest at the early vegetative, late vegetative and anthesis stages of development were all significantly (P = 0.01) different from each other and from those of the control (Table 12). For both virus-free and virus-carrying aphids, the growth of axillary shoots of beans infested with six aphids each was significantly (P = 0.01) smaller than those of plants infested with three aphids each when *A. fabae* were infested to the plants at the early vegetative and late vegetative stages of development. This difference was not significant for plants attacked by the aphids at the anthesis and grain filling stages of development at P = 0.05 (Table 12). Furthermore, for beans infested with *A. fabae* at the levels of six and three aphids per plant, the length of axillary shoots of plants infested with virus-carrying aphids was significantly (P = 0.01) shorter than those of plants infested with virus-free aphids, when the aphids were introduced at the early vegetative, late vegetative and anthesis stages of development. Plants infested with virus-carrying aphids at the grain filling stage were not significantly ($P<0.05$) affected by the virus transmitted (Table 12).

The results obtained (Table 12) indicated that the stage of development at which aphids were infested to beans, accounting for 94.2% of the total variation in the growth of axillary shoots due to the treatments imposed, was the most important factor determining shoot damage by <u>A. fabae</u>. The results further indicated that both the level of aphid infestation and the transmission of Common Bean Mosaic virus were important only when aphids were infested to the plants at the early vegetative, late vegetative and anthesis stages of development.

The influence on the flowering of beans when the plants were infested with virus-free and virus-carrying aphids at the two levels of <u>A. fabae</u> populations during four stages of development is presented in Table 13. These results, Table 13, showed that the mean number of flowers produced per plant was greatly reduced for bean plants attacked by the aphids at the early vegetative and late vegetative stages of development. Plants infected by the Common Bean Mosaic virus produced the smallest

Table 12: The means and analysis of variance of the length (cm) of axillary shoots of beans infested with virus free and virus carrying aphids at two levels of *A. fabae* populations during four stages of plant development.

a) analysis of variance of length (cm) of axillary shoots

source of variation	df	SS	MS	F
total	95	231855.96		
stage of development (S)	(3)	209245.04		
linear	1	193523.01	193523.01	1535.99**
quadratic	1	15606.00	15606.00	127.90**
cubic	1	116.03	116.03	0.95
virus status (V)	1	5400.00	5400.00	44.25**
level of infestation (L)	1	1890.38	1890.38	15.49**
interaction S x V	3	3334.25	1111.42	9.11**
interaction S x L	3	1997.71	665.90	5.46**
interaction V x L	1	112.66	112.66	0.92
interaction V x L x S	3	113.92	44.64	0.37
error	80	9762.00	122.02	

**significant at P = 0.01; CV = 11.44%

SE stage mean = 2.255 cm SE (status or level) means = 0.627 cm

b) mean length (cm) of axillary shoots of beans.

virus status	aphid level	stage of bean development			
		early vegetative	late vegetative	anthesis	grain filling
virus-free	6 (high)	13.33a	102.50b	136.83c	144.33d
	3 (low)	43.67a	110.50b	137.17c	144.83d
virus-carrying	6 (high)	8.50a	72.33b	118.33c	143.60d
	3 (low)	26.67a	77.33b	119.17c	146.33c

LSD between (status or level) means 0.05 = 1.77 cm
0.01 = 2.36 cm

a,b,c,d: for each level of aphid infestation, means denoted by the same letter are not significantly (P = 0.05) different (Duncan's New Multiple Range test).

number of flowers, and on some of the plants infected at the early vegetative stage, near total loss of flowering occurred. Generally, plants infested with six aphids each produced fewer flowers than those infested with three aphids each.

The analysis of variance (Table 13) showed that the linear and quadratic effects on flower production for the stage of development at which the aphids were infested to the plants were highly significant at P = 0.01. Although the cubic effect of stage of development was also highly significant (P = 0.01), its sum of squares was only 6.0% of the total sum of squares for the stage of development. The sum of squares for the stage of development accounted for 90.6% of the total sum of squares due to the treatments imposed. The analysis of variance also showed that the influence on flowering of the virus status of the aphids, the interactions between the stage of development and virus transmission, and of all the three factors were highly significant at P = 0.01. However, they accounted for only 3.1%, 4.5% and 1.7% respectively of the total sum of squares due to the treatments imposed on the beans. The level of A. fabae infestation and the effects of the interactions between stage of development and level of aphid infestation, and between level of infestation and virus status of the aphids did not significantly influence the flowering of beans at P = 0.05 (Table 13).

The comparison of the mean number of flowers produced per plant (Table 13) revealed that for beans infested with virus-free and virus-carrying aphids at the levels of six and three individuals per plant, the number of flowers produced was significantly (P = 0.01) different for plants attacked by *A. fabae* at the early vegetative, late vegetative and anthesis stages of development when compared to each other and when compared to plants infested at the grain filling stage. For beans infested with *A. fabae* at the two levels of populations, plants infested with virus-carrying aphids produced significantly (P = 0.01) fewer flowers than those infested with virus-free aphids when the infestation was carried out at the early vegetative and late vegetative stages. Infestation at the anthesis and grain filling stages of development did not result in significant difference in flowering at P = 0.05 (Table 13).

When virus-free aphids were infested to beans at the early vegetative stage, plants infested with six aphids each produced significantly ($P = 0.05$) fewer flowers than those infested with three aphids each (Table 13). This difference was not significant ($P<0.05$) when Common Bean Mosaic virus was transmitted to the plants. However, when the plants were attacked by aphids at the late vegetative stage, plants infested with the higher level of aphids produced significantly ($P = 0.01$) fewer number of flowers than those infested with the lower number of insects for both virus-free and virus-carrying aphids. There was no significant ($P<0.05$) difference in the number of flowers produced when the plants were attacked by the aphids at the anthesis and grain filling stages of development (Table 13).

The results presented in Table 13 clearly indicated that the stage of development at which the aphids were infested to the plants was the most important factor influencing aphid damage to flowering in beans. It accounted for 90.7% of the total variation in flowering due to the treatments imposed. The results further indicated that plants infected by the Common Bean Mosaic virus only suffered severe reduction in flowering whe the virus-carrying aphids were infested to the plants at

Table 13: The means and analysis of variance of the number of flowers produced per plant when virus-free and virus-carrying aphids were infested to beans at two levels of *A. fabae* populations during four stages of plant development.

a) analysis of variance of number of flowers per plant.

source of variation	df	SS	MS	F
total	95	75662.73		
stage of development (S)	(3)	67436.86		
linear	1	61676.00	61676.00	3953.39**
quadratic	1	1708.59	1708.59	109.53**
cubic	1	4052.28	4052.28	259.76**
virus status (V)	1	2271.76	2271.76	145.57**
level of infestation (L)	1	25.01	25.01	1.60
interaction S x V	3	3360.20	1130.06	71.77**
interaction S x L	3	50.95	16.98	1.09
interaction V x L	1	2.34	2.34	0.15
interaction V x L x S	3	1257.11	419.04	26.85**
error	80	1248.50	15.60	

** significant at P = 0.01; CV = 8.92%
SE stage mean = 0.806; SE (status or level) mean = 0.570.

b) mean number of flowers produced per plant.

virus status	aphid level	stage of bean development: early vegetative	late vegetative	anthesis	grain filling
virus-free	6 (high)	13.00a	41.33b	67.67c	71.01
	3 (low)	14.67a	44.17b	69.50c	71.34c
virus-carrying	6 (high)	3.67a	12.00b	69.12c	71.67c
	3 (low)	3.83a	16.13b	68.67c	70.93c

LSD between (status or level) means. 0.05 = 1.61
0.01 = 2.14

a,b,c,d: for each level of aphid infestation, means denoted by the same letter are not significantly (P = 0.05) different (Duncan's New Multiple Range test).

the pre-flowering stages of bean development.

The influence on the number of pods produced per plant when virus-free and virus-carrying *A. fabae* were infested to beans at the levels of six and three aphids per plant during four stages of development is given in Table 14. The mean number of pods produced per plant (Table 14) showed that bean plants suffered severe aphid damage when the pests were infested to them at the early vegetative and late vegetative stages of development. Pod production was also substantially reduced on bean plants attacked by the aphids during the anthesis stage. Damage to pod production was more severe when the aphids transmitted the Common Bean Mosaic virus than when virus-free aphids were infested to the plants. Furthermore, the higher level of *A. fabae* infestation resulted in more severe damage (Table 14).

The analysis of variance (Table 14) showed a highly significant (P = 0.01) linear effect on the number of pods produced per plant for the stage of development at which the aphids were infested to the plants. The quadratic and cubic effects for stage of development were not significant at P = 0.05. The sum of squares for stage of development at which the aphids were infested to the plants was 87.3% of the total sum of squares for the treatments. The analysis further showed that the production of pods by bean plants was also significantly (P = 0.01) influenced by the level of *A. fabae* populations, the virus status of the aphids and by the effects of the interaction between the stage of bean development and the virus status of the aphids. Their sums of squares were 4.0%, 2.3% and 4.0% respectively of the total sum of squares due to the treatments imposed. The effects on pod production of the interactions between the stage of bean development and level of *A. fabae* infestation, and between the virus status of the aphids and level of aphid infestation were not significant at P = 0.05 (Table 14).

When beans were infested with virus-free and virus-carrying *A. fabae* at the levels of six and three aphids per plant, the mean number of pods produced per plant was significantly (P = 0.01) different for plants attacked by the pest at the early vegetative, late vegetative and anthesis stages of development when compared to each other and when compared to those infested at the grain filling stage of development (Table 14). For plants infested with the aphids at both levels of populations, the reduction in pod yield was significantly (P = 0.01) greater on plants infested with virus-carrying aphids than on those infested with virus-free aphids when the aphids were infested to the beans at the early vegetative, late vegetative and anthesis stages of development. This difference was not significant ($P < 0.05$) for plants attacked by aphids at the grain filling stage (Table 14).

When beans were infested with virus-free *A. fabae* at the level of six and three aphids per plant, plants infested with six aphids each at the early vegetative and anthesis stages of development produced significantly (P = 0.01) fewer number of pods than those infested with three aphids each. This difference was not significant for infestation carried out at the grain filling stage at P = 0.05 (Table 14). However, when the aphids used transmitted the Common Bean Mosaic virus, the difference in pod production between plants infested with six and three aphids each during the different stages of development was not significant at P = 0.05.

The results presented in Table 14 indicated that the greatest proportion of variation in pod yield of beans as a result of the treatments imposed, 87.3%, was due to the stage of development at which *A. fabae*

Table 14: The means and analysis of variance of the number of pods produced per plant when virus-free and virus-carrying aphids were infested to beans at two levels of *A. fabae* populations during four stages of plant development.

a) analysis of variance

source of variation	df	SS	MS	F
total	95	959.22		
stage of development (S)	(3)	740.11		
linear	1	737.55	737.55	526.82**
quadratic	1	1.26	1.26	0.90
cubic	1	1.30	1.30	0.93
virus status (V)	1	33.84	33.84	24.21**
level of infestation (L)	1	19.26	19.26	13.78**
interaction S x V	3	33.84	11.29	8.03**
interaction S x L	3	8.62	2.87	2.05
interaction V x L	1	2.34	2.34	1.67
interaction V x L x S	3	9.36	3.12	2.23
error	80	111.85	1.40	

**significant at P = 0.01; CV = 20.46%
SE stage mean = 0.242; SE (status or level) mean = 0.171

b) mean number of pods produced per plant.

virus status	aphid level	stage of bean development			
		early vegetative	late vegetative	anthesis	grain filling
virus-free	6 (high)	2.08a	4.67b	6.67c	9.83d
	3 (low)	4.83a	6.33b	7.50c	9.83d
virus-carrying	6 (high)	0.83a	2.89b	7.12c	9.53d
	3 (low)	1.33a	3.36b	6.68c	9.36d

LSD between (status or level) means 0.05 = 0.48
0.01 = 0.64

a,b,c,d: for each level of aphid infestation, means denoted by the same letter are not significantly (P = 0.05) different (Duncan's New Multiple Range test).

were infested to the plants. The results also indicated that the infection of plants by the Common Bean Mosaic virus increased the severity of the effects of aphid attack on pod yield; it also reduced the difference in plant response due to the level of aphid populations.

The influence of A. fabae infestation on the number of seeds produced per plant when virus-free and virus-carrying aphids were infested to beans at the level of six and three aphids per plant during different stages of development is shown in Table 15. The mean number of seeds produced per plant (Table 15) showed that seed production was most severely reduced on plants attacked by the aphids during the early vegetative and late vegetative stages of development. Infestation at the anthesis stage also caused serious reduction in seed production. The Common Bean Mosaic virus transmitted to the plants by the aphids increased the severity of damage caused to the plants by aphid attack. The reduction in the number of seeds produced per plant was also generally greater for beans infested with six aphids each than for those infested with three aphids each (Table 15).

It was shown by the analysis of variance

(Table 15) that the linear effect on the number of seeds produced per plant for the stage of development at which the aphids were infested to the plants was highly significant at P = 0.01. The quadratic and cubic effects for the stage of development were however not significant at P = 0.05. The sum of squares for the stage of development at which the aphids were infested to the plants was 91.8% of the total sum of squares for the treatments. The analysis further showed that the number of seeds produced per plant was significantly (P = 0.01) influenced by the level of A. fabae infestation, the virus status of the aphids, and by the effects of the interaction between the stage of bean development and level of aphid infestation. However, they accounted for only 1.6%, 2.6% and 2.6% respectively of the treatment sum of squares. The effects of the interaction between the stage of bean development and level of A. fabae infestation, stage of development and the virus status of the aphids, and of all three factors on the number of seeds produced per plant were not significant at P = 0.05 (Table 15).

The comparison of the mean number of seeds produced per plant (Table 15) revealed that for beans infested with virus-free or virus-carrying *A. fabae* at the levels of six and three individuals per plant, the number of seeds produced per plant was significantly (P = 0.01) different for beans attacked by the aphids at the early vegetative, late vegetative and anthesis stages of development when compared to each other and when compared to the control. It was further shown that at both levels of *A. fabae* populations, plants infested with virus-carrying aphids produced significantly (P = 0.01) fewer number of seeds than those infested with virus-free aphids when the infestations were carried out at the early vegetative and late vegetative stages of development. For plants attacked by the pest at the anthesis and grain filling stages, this difference was not significant at P = 0.05. When virus-free aphids were used to infest the beans, seed yield of plants infested with six aphids each was significantly (P = 0.01) smaller than those of plants infested with three aphids each for plants attacked by the insects at the early vegetative, late vegetative, and anthesis stages of development, but was not significant (P<0.05) when the infestation was carried out at the grain filling stage (Table 15). When virus-carrying aphids were used however, this difference was only significant ($P = 0.01$) for infestation that occurred at the anthesis stage of development.

It was indicated by these results (Table 15) that the stage of plant development at which aphid attack occurred was the most important source of variation in the number of seeds produced when bean plants were attacked by A. fabae, as it accounted for 91.8% of the total variation due to the treatments imposed. The results also indicated that the transmission of Common Bean Mosaic virus increased the effects of aphid infestation and reduced the difference in seed yield due to the levels of A. fabae infestation.

The overall effects on the weight of seeds produced per plant when virus-free and virus-carrying A. fabae were infested to beans at the levels of six and three aphids per plant during four stages of development is shown in Table 16. The results (Table 16) showed that the weight of seeds produced per plant was greatly reduced on plants attacked by the aphids at the early vegetative, late vegetative and anthesis stages of development.

Table 15: The means and analysis of variance of the number of seeds produced per plant when virus-free and virus-carrying aphids were infested to beans at two levels of *A. fabae* populations during four stages of plant development.

a) analysis of variance of number of seeds per plant

source of variation	df	SS	MS	F
total	95	16951.33		
stage of development (S)	(3)	13438.33		
linear	1	13356.30	13356.30	462.15**
quadratic	1	54.00	54.00	1.87
cubic	1	28.03	28.03	0.97
virus status (V)	1	376.04	376.04	13.01**
level of infestation (L)	1	234.38	234.38	8.11**
interaction S x V	3	380.12	124.71	4.33*
interaction S x L	3	92.46	30.82	1.07
interaction V x L	1	20.17	20.17	0.70
interaction V x L x S	3	97.50	32.50	1.12
error	80	2312.33	28.90	

significant *P = 0.05; ** P = 0.01 CV = 26.20%
SE stage mean = 1.097; SE status or level mean = 0.776

b) mean number of seeds produced per plant

virus status	aphid level	stage of bean development			
		early vegetative	late vegetative	anthesis	grain filling
virus-free	6 (high)	5.01a	15.50b	23.83c	36.13d
	3 (low)	13.83a	20.67b	27.53c	37.83d
virus-carrying	6 (high)	1.17a	9.01b	22.88c	36.07d
	3 (low)	3.03a	10.17b	27.60c	37.53d

LSD between (status or level) mean 0.05 = 2.20
0.01 = 2.92

a,b,c,d: for each level of aphid infestation, means denoted by the same letter are not significantly (P = 0.05) different (Duncan's New Multiple Range test).

The reduction in seed yield was more severe on plants to which the aphids transmitted the Common Bean Mosaic virus. The weight of seeds produced per plant was generally smaller for beans infested with six aphids per plant than for those infested with three aphids each.

The analysis of variance (Table 16) showed a highly significant (P = 0.01) linear effect on seed yield for the stage of development at which A. fabae were infested to the plants. The quadratic and cubic effects for the stage of development were not significant at P = 0.05. The sum of squares for the stage of development accounted for 88.1% of the total sum of squares for the treatments. It was also shown by the analysis that the weight of seeds produced per plant was influenced significantly (P = 0.01) by the level of A. fabae infestation, the virus status of the aphids, and by the effects of the interaction between the stage of bean development and the virus status of the aphids at P = 0.05 (Table 16). However, these accounted for only 1.8%, 5.3% and 5.1% respectively of the total sum of squares due to the treatments imposed. The effects of the interactions between stage of bean development and the level of A. *fabae* infestation, the virus status of the aphids and the level of infestation, and between all the three factors were not significant at P = 0.05 (Table 16).

When virus-free and virus-carrying aphids were infested to beans at the level of six and three individuals per plant, the mean weight of seeds produced by the plants were significantly (P = 0.01) different for plants attacked by the aphids at the early vegetative, late vegetative and anthesis stages of development when compared to each other and when compared to plants infested with the pest at the grain filling stage (Table 16). For both levels of aphid infestations, plants infested with virus-carrying insects produced seeds of significantly (P = 0.01) smaller weight as compared to plants infested with virus-free aphids when the infestations were effected at the early vegetative and late vegetative stages of development. This difference was not significant (P<0.05) for plants attacked by aphids during the anthesis and grain filling stages of development (Table 16).

When virus-free aphids were infested to beans at the early vegetative, late vegetative and anthesis stages of development, *A. fabae* infested to the plants at the level of six individuals per plant caused significantly (P = 0.01) greater reduction in the weight of seeds produced than those infested at the level of three individuals per plant. This difference was not significant (P<0.05) for plants infested at the grain filling stage (Table 16). When the *A. fabae* used transmitted the Common Bean Mosaic virus however, the corresponding difference was only significant (P = 0.01) for plants attacked by the aphids at the late vegetative and anthesis stages of development (Table 16).

The results presented in Table 16 indicated that the stage of development at which the aphids were infested to the beans was the most important factor determining seed yield, as it accounted for 85.6% of the total variation in the weight of seeds produced per plant as a result of the treatments imposed. The results further indicated that virus transmission by the aphids increased the effect of infestation and reduced the difference in seed yield due to the levels of *A. fabae* populations used.

The means obtained from these studies for the various parameters of plant growth, reproduction and yield when virus-free and virus-carrying *A. fabae*

Table 16: The means and analysis of variance of the weight (gm) of seeds produced per plant when virus-free and virus carrying aphids were infested to beans at two levels of A. fabae populations during four stages of plant development.

a) analysis of variance of weight (gm) of seeds per plant.

source of variation	df	SS	MS	F
total	95	6439.89		
stage of development (S)	(3)	5129.35		
linear	1	5059.48	5059.48	658.79**
quadratic	1	69.83	69.83	9.09**
cubic	1	0.04	0.04	0.01
virus status (V)	1	225.40	225.40	29.30**
level of infestation (L)	1	143.72	143.72	18.70**
interaction S x V	3	235.52	78.51	10.22**
interaction S x L	3	68.28	22.76	2.96
interaction V x L	1	6.36	6.36	0.83
interaction V x L x S	3	16.50	5.50	0.72
error	80	614.76	7.68	

significant at P = 0.01; CV = 22.45%
SE stage mean = 0.566gm; SE(status or level)mean = 0.400 gm

b) mean weight (gm) of seeds produced per plant.

virus status	aphid level	stage of bean development			
		early vegetative	late vegetative	anthesis	grain filling
virus-free	6 (high)	3.67a	10.53b	12.41c	23.12d
	3 (low)	8.47a	13.17b	17.10c	22.84d
virus-carrying	6 (high)	0.38a	3.93b	11.94c	22.82d
	3 (low)	1.43a	5.62b	16.98c	23.09d

LSD between (status or level) means 0.05 = 1.13 gm
0.01 = 1.51 gm

a,b,c,d: for each level of aphid infestation, means denoted by the same letter are not significantly (P = 0.05) different (Duncan's New Multiple Range test).

were infested to beans at the levels of six and three individuals per plant during four stages of plant development are summarised in Appendix Table III. The analysis of variance for the various parameters are also summarised in Appendix Table IV.

It was shown by the means for the various characters (Appendix Table III) that in general, A. fabae attack on beans caused severe damage to the plants when infestation occurred at the early vegetative, late vegetative and anthesis stages of development. For the height of central shoots, and number of flowers produced per plant, serious damage occurred when aphids were introduced onto the plants at the early vegetative and late vegetative stages, but damage was smaller when the infestation occurred at the anthesis stage. For the remaining characters, namely, length of axillary shoots, number of pods per plant, number of seeds per plant and weight of seeds per plant, damage was severe when the plants were attacked by the aphids at the early vegetative, late vegetative, and anthesis stages of development.

The analysis of variance (Appendix IV) showed a highly significant ($P = 0.01$) linear effects for all the parameters measured. However, although the cubic effect was significant (P = 0 01) for the number of flowers produced per plant its sum of squares was only 6.0% of the total sum of squares due to the stage of development.

The analysis further showed that the influence of the virus status of the aphids was highly significant (P = 0.01) for all the characters except the height of central shoots and number of flowers per plant. Whereas the effects of the interactions between the stage of bean development and virus status of the aphids were significant ($P \geq 0.05$) for all the plant parameters except the height of central shoots, the only other interaction effects which were significant (P = 0.01) were those of the stage of bean development and level of infestation on the length of axillary shoots, and of all the three factors on the number of flowers produced per plant.

The results of aphid damage in terms of the growth, reproduction and yield of beans indicated that A. fabae attack on the plants at the early vegetative, late vegetative and anthesis stages of development were the most important for direct aphid injury and the transmission of Common Bean Mosaic virus. The results also indicated that virus infection of beans during these stages of development increased the severity of aphid attack, and reduced the difference in damage due to the levels of pest populations. Plants suffered little from aphid attack and virus infection when the insects were infested to them at the grain filling stage of development.

4:3:3 The influence on the growth, development and yield of common beans (*P. vulgaris*) of two levels of soil moisture and soil fertility, and the infestation of bean plants with four *A. fabae* each during four stages of growth and development.

The results of the growth of the central shoots of beans grown using two levels of soil moisture and fertility as influenced by *A. fabae* infestation on the plants at four stages of development is presented in Table 17. These results, Table 17, showed that bean plants supplied with 0.5ℓ of water per week or grown without fertilizer suffered a substantially retarded growth when compared to those that received 2.0ℓ of water per week or 10.0g of DAP fertilizer. For both levels of soil moisture and soil fertility, plants infested with four aphids each at the early vegetative and late vegetative stages of development suffered large reductions in the growth of central shoots. Smaller but substantial reduction in the growth of central shoots also occurred when the aphids were introduced onto the plants at the anthesis stage.

The analysis of variance (Table 17) revealed that the influence of both the levels of soil moisture and soil fertility on the growth of central shoots of beans was highly significant at P = 0.01. The two treatments accounted for 23.9% and 9.8% respectively of the total sums of squares due to the treatment imposed on the beans. The analysis further showed a highly significant (P = 0.01) linear effect on the growth of central shoots for the stage of development at which the insects were infested to the plants. The quadratic and cubic effects of stage of development were however not significant at P = 0.05 (Table 17). The sum of squares for stage of development was 51.4% of the treatment sum of squares. It was also shown that the effects of the interactions between the stage of bean development and level of fertility, stage of development and level of soil moisture, levels of fertility and soil moisture, and of all the three factors on the growth of central shoots of beans were highly significant at P = 0.01 (Table 17). Their respective sums of squares were however only 2.6%, 3.8%, 3.3% and 5.2% of the total sum of squares due to the treatments imposed.

Comparison of the mean height of central shoots (Table 17) showed that the growth of shoots of bean plants supplied with 2.0ℓ of water per week was significantly (P = 0.01) greater than those of plants supplied with 0.5ℓ of water per week, regardless of the level of soil fertility and the stage of development at which the aphids were infested to the plants. When the plants were raised using the higher level of soil moisture, the growth of central shoots of those plants that received 10.0 g of fertilizer was significantly (P = 0.01) greater than those of plants grown without fertilizer regardless of the stage of development at which A. fabae infestation was carried out. However, when the moisture supply was 0.5ℓ per week this difference was not significant (P< 0.05). for plants attacked by aphids at the grain filling stage (Table 17).

For bean plants raised without fertilizer and watered at the level of 0.5ℓ per week, the difference in the growth of central shoots of plants attacked by the aphids at the early vegetative, late vegetative and anthesis stages were hightly significant (P = 0.01) when compared to each other and when compared to the control. However, when the plants received 2.0ℓ of water per week, the difference in growth between those attacked by *A. fabae* at the late vegetative, and anthesis stages were not significant at P = 0.05 (Table 17).

When beans were grown using 10.0 g of DAP fertilizer and supplied with 2.0ℓ of water per week, the difference in growth of the central shoots was highly significant (P = 0.01) for plants attacked by aphids at the early vegetative, late vegetative and anthesis stages of development when compared to each other and when compared to plants infested with the insects at the grain filling stage. However, when the plants received 10.0g of fertilizer but only 0.5ℓ of water per week, the difference in growth between plants attacked by aphids at the anthesis and grain filling stages were not significant at P = 0.05 (Table 17).

The results obtained in these experiments (Table 17) indicated that the growth of central shoots of beans was greatly influenced by all the treatments imposed. It was further indicated that low levels of soil moisture resulted in limited growth of the beans, and influenced bean response to level of soil fertility and to aphid attack. The results also indicated that the growth of central shoots of beans was most severely affected when the aphids attacked the plants at the early vegetative, late vegetative and anthesis stages of development.

The production of flowers by bean plants as affected by the conditions of soil moisture and soil fertility under which the plants were grown, and by the stage of development at which A. fabae were infested to beans is shown in Table 18. The results (Table 18) showed that plants grown without fertilizer or supplied with 0.5ℓ of water per week produced much fewer flowers than those grown using 10.0g of DAP fertilizer or supplied with 2.0ℓ of water per week. The bean plants generally suffered serious reduction in flowering when A. fabae were

Table 17: The means and analysis of variance of the heights (cm) of central shoots of beans grown using two levels of soil moisture and soil fertility and infested with _A. fabae_ during four stages of plant development.

a) analysis of variance of height (cm) of central shoots

source of variation		df	SS	MS	F
total		95	354302.34		
stage of bean development (S)		(3)	161997.50		
	linear	1	160089.70	160089.70	326.40**
	quadratic	1	360.38	360.38	0.73
	cubic	1	1548.05	1548.05	3.15
level of soil fertility (F)		1	30960.21	30960.21	63.12**
level of soil moisture (M)		1	75152.08	75152.08	153.23**
interaction S x F		3	8084.29	2694.77	5.49**
interaction S X M		3	11919.45	3973.28	8.10**
interaction F x M		1	10416.62	10416.62	21.24**
interaction F x M x S		3	16534.85	5511.62	11.24**
error		80	39237.34	490.47	

CV = 16.21%

SE stage mean = 4.521 cm;
**significant at P = 0.01; SE fertility and moisture mean = 3.197 cm

b) mean height (cm) of central shoots of beans.

level of fertilizer	level of moisture	stage of bean development			
		early vegetative	late vegetative	anthesis	grain filling
0.0g	0.5ℓ	41.50^{a}	86.01^{b}	126.00^{c}	148.83^{d}
	2.0ℓ	94.33^{a}	135.17^{b}	141.17^{b}	174.17^{c}
10.0g	0.5ℓ	73.67^{a}	99.17^{b}	140.67^{c}	151.17^{c}
	2.0ℓ	118.33^{a}	164.83^{b}	184.33^{c}	306.33[illegible]

LSD between (fertility, and moisture) means 0.05 = 9.04 cm
0.01 =12.03 cm

a,b,c,d: for each level of soil moisture, means denoted by the same letter are not significantly (P = 0.05) different (Duncan's New Multiple Range test).

infested to them at the early vegetative and late vegetative stages. The number of flowers produced by plants attacked by *A. fabae* at the anthesis and grain filling stages were however similar (Table 18).

The analysis of variance of the number of flowers produced per plant (Table 18) showed that the levels of soil moisture and soil fertility significantly (P = 0.01) influenced bean flowering. However, their sums of squares were only 3.9% and 0.4% respectively of the treatment sum of squares. The analysis further showed highly significant (P = 0.01) linear, quadratic and cubic effects on flowering for the stage of development at which the aphids were infested to the plants. Although the cubic effect was highly significant (P = 0.01), its sum of squares was only 1.7% of the sum of squares due to the stage of development, and the means (Table 18) did not show a cubic trend. The sum of squares due to the stage of development at which the aphids were infested to the plants was 92.2% of the treatment sum of squares. It was also shown by the analysis that the production of flowers by beans was significantly (P = 0.05) influenced by the effects of the interactions between the stage of bean development and level of soil moisture, levels of soil fertility and soil moisture, and between all the three factors. The effects of the interaction between the stage of bean development and level of soil fertility was not significant at P = 0.05 (Table 18). The total sum of squares for all the interactions was however only 0.5% of the treatment sum of squares.

The means of the number of flowers produced per plant (Table 18) showed that flower production of plants that received 2.0ℓ of water per week was significantly (P = 0.01) greater than those of plants that received 0.5ℓ of water per week, for both levels of soil fertility and regardless of the stage of development at which *A. fabae* attacked the plants.

For bean plants watered at the level of 0.5ℓ per week, those supplied with 10.0g of fertilizer produced significantly (P = 0.01) greater number of flowers than the ones grown without fertilizer when aphids were infested to them at the late vegetative, anthesis and grain filling stages of development. This difference was not significant

(P<0.05) for plants attacked by the pest at the early vegetative stage (Table 18). For the watering level of 2.0ℓ per week, however, flower production by the plants supplied with 10.0 g of fertilizer was significantly (P = 0.01) greater than that of plants grown without fertilizer when the aphids were infested to them at the early vegetative and late vegetative stages of development. However, this was not significant (P = 0.05) when the infestation was carried out at the anthesis and grain filling stages (Table 18).

When beans were grown under both levels of soil fertility and watered using 0.5ℓ and 2.0ℓ per week, plants attacked by A. fabae at the early vegetative and late vegetative stages of development produced significantly (P = 0.01) different number of flowers when compared to each other and when compared to those attacked by the aphids at the anthesis and grain filling stages (Table 18). There were no significant (P<0.05) differences in flowering for plants infested with the pest during the anthesis and grain filling stages of development.

The results presented in Table 18 indicated that the levels of soil moisture and soil

Table 18: The means and analysis of variance of the number of flowers per plant when bean plants grown using two levels of soil moisture and soil fertility were infested with A. fabae during four stages of development.

a) analysis of variance of number of flowers per plant.

source of variation	df	SS	MS	F
total	95	117551.22		
stage of bean development (S)	(3)	110254.78		
linear	1	99216.25	9216.25	4493.49**
quadratic	1	9106.51	9106.51	412.41**
cubic	1	1932.02	1932.02	87.50**
level of soil fertility (F)	1	446.34	446.34	20.21**
level of soil soil moisture (M)	1	4496.34	4496.34	203.63**
interaction S x F	3	44.03	14.68	0.66
interaction S x M	3	253.85	84.62	3.83*
interaction F x M	1	71.76	71.76	3.25*
interaction F x M x S	3	217.61	72.58	3.29*
error	80	1766.50	22.08	

significant *at P = 0.05; **at P = 0.01· CV = 7.55%
SE of stage mean = 0.959 SE fertility or moisture mean = 0.678

b) mean number of flowers produced per plant.

level of fertilizer	level of moisture	stage of bean development			
		early vegetative	late vegetative	anthesis	grain filling
0.0g	0.5ℓ	5.50a	40.83b	81.33c	81.67c
	2.0ℓ	12.33a	55.67b	100.33c	101.67c
10.0g	0.5ℓ	6.17a	52.38c	86.83c	88.67c
	2.0ℓ	20.33a	58.33b	101.35c	102.28c

LSD between (fertility, and moisture) means 0.05 = 1.92
0.01 = 2.55

a,b,c; for each level of soil moisture, means denoted by the same letter are not significantly (P = 0.05) different (Duncan's New Multiple Range test).

fertility, and the stage of development at which *A. fabae* attacked the beans all seriously influenced flowering in beans. The results further indicated that higher levels of soil moisture and soil fertility enhanced plant vigour, increased flower production by plants and reduced the overall effects of aphid infestation. The reduction in flowering was shown to be most severe when the aphids were infested to beans at the early vegetative and late vegetative stages of development.

The production of pods by beans as influenced by the levels of soil moisture and soil fertility, and by the stage of development at which *A. fabae* were infested to the plants is given in Table 19. These results (Table 19) showed that lower levels of soil moisture or soil fertility limited the production of pods by beans. Relatively large reduction in pod yield occurred on all the plants that suffered aphids attack at the early vegetative, late vegetative and anthesis stages of development (Table 19).

The analysis of variance (Table 19) revealed that the influence of the levels of soil moisture and soil fertility on the number of pods produced per plant was highly significant at P = 0.01. The sums of squares due to the two treatments were 56.5% and 13.0% of the total sum of squares for the treatments. The analysis also showed highly significant (P = 0.01) linear and quadratic effects on pod yield for the stage of development at which A. fabae were infested to the plants. The cubic effect for stage of development was not significant at P = 0.05. The sum of squares for the stage of development was 24.9% of the treatments sum of squares. The analysis further showed that only the effect on pod yield of the interaction between the stage of bean development and level of soil moisture was significant at P = 0 01. Its sum of square accounted for 3.9% of the treatment sum of squares. The effects of the remaining interactions were not significant at P = 0.05, and their combined sums of squares were only 1.5% of the total sum of squares due to the treatments imposed.

The comparison of the mean number of pods produced (Table 19) showed that bean plants grown using 10.0g of fertilizer and watered at the level of 2.0ℓ per week produced significantly (P = 0.01) larger number of pods than those grown without fertilizer or supplied with only 0.5ℓ of water per week, irrespective of the stage of development at which the aphids were infested to them.

When bean plants grown without fertilizer were supplied with 0.5ℓ of water per week, the number of pods produced per plant was significantly ($P = 0.01$) smaller for plants infested with <u>A. fabae</u> at the early vegetative stage as compared to those of plants attacked by the pest at the late vegetative, anthesis and grain filling stages of development. The production of pods by plants attacked by the aphids during the late vegetative, anthesis and grain filling stages of development was not significantly different at $P = 0.05$ (Table 19). However, when the plants received 2.0ℓ of water per week, aphid infestation on beans at the early vegetative and late vegetative stages of development resulted in pod yields that were significantly ($P = 0.01$) smaller than for plants attacked at the anthesis and grain filling stages. The difference in pod production between plants attacked by aphids at the early vegetative and late vegetative stages, and between anthesis and grain filling stages of development were not significant at $P = 0.05$

Table 19).

The results obtained (Table 19) further showed that when bean plants grown using 10.0g for DAP fertilizer received 0.5ℓ of water per week, pod production of plants bearing A. fabae at the early vegetative, late vegetative and anthesis stages were significantly (P = 0.01) smaller than those of plants infested at the grain filling stage. The number of pods produced by plants infested at the early vegetative stage was also significantly (P = 0.01) smaller than those of plants attacked at the anthesis stage (Table 19). However, pod production of plants attacked by aphids at the late vegetative stage was not significantly (P<0.05) different from those of plants that suffered infestation at the early vegetative and anthesis stages of development. Whereas, when beans grown under the high level of fertility were supplied with 2.0ℓ of water, A. fabae infestation at the early vegetative, late vegetative and anthesis stages all resulted in significantly (P = 0.01) fewer number of pods per plant than for the control. However, the pod yield of plants attacked by the aphids at the early vegetative and late vegetative stages were not significantly (P<0.05) different from each other but were significantly different from those of plants infested at the anthesis stage at (P = 0.01) (Table 19).

The results presented in Table 19 indicated that all the three treatments of levels of soil moisture and soil fertility, and the stage of development at which the aphids were infested to the plants greatly influenced pod production in beans. However, soil moisture and aphid infestation were the most important factors that affected pod production. The results also indicated that damage caused by *A. fabae* attack was most severe on plants attacked by the pest at the early vegetative, late vegetative and anthesis stages of development.

The overall effect of damage caused to beans in terms of the number of seeds produced per plant when bean plants grown under two levels of soil moisture and soil fertility were infested with *A. fabae* at four stages of development is presented in Table 20. These results (Table 20) showed that both low levels of soil moisture and soil fertility substantially reduced seed production in beans. It also showed that for both levels of soil fertility and soil moisture, bean infestation with the aphids

Table 19: The means and analysis of variance of the number of pods produced per plant when bean plants grown using two levels of soil moisture and soil fertility were infested with A. fabae during four stages of development.

a) analysis of variance of number of pods per plant.

source of variation	df	SS	MS	F
total	95	1375.96		
stage of bean development (S)	(3)	286.46		
linear	1	261.07	261.07	93.57**
quadratic	1	18.38	18.38	6.59**
cubic	1	7.01	7.01	2.51
level of soil fertility (F)	1	150.00	150.00	53.72**
level of soil moisture (M)	1	651.04	651.04	233.18**
interaction S X F	3	14.67	4.89	1.75
interaction S X M	3	45.46	15.15	5.43**
interaction F x M	1	4.17	4.17	1.49
interaction F x M x S	3	0.83	0.28	0.10
error	80	223.33	2.79	

**significant at P = 0.01 CV = 22.29%
SE stage mean = 0.341; SE fertility and moisture mean = 0.241

b) mean number of pods per plant.

level of fertilizer	level of moisture	stage of bean development			
		early vegetative	late vegetative	anthesis	grain filling
0.0g	0.5ℓ	2.33[a]	3.83[b]	4.35[b]	4.82[b]
	2.0ℓ	7.00[a]	7.33[a]	8.38[b]	11.79[b]
10.0g	0.5ℓ	4.08[a]	5.67[ab]	5.88[b]	8.17[c]
	2.0ℓ	9.12[a]	9.83[a]	11.17[b]	16.21[c]

LSD between (fertility, and moisture) means 0.05 = 0.68.
0.01 = 0.91

a,b,c: for each level of soil moisture, means denoted by the same letter are not significantly (P = 0.05) different (Duncan's New Multiple Range test).

at the early vegetative, late vegetative and anthesis stages of development resulted in serious reduction in the number of seeds produced per plant relative to the control.

The analysis of variance (Table 20) showed that the number of seeds produced per plant was significantly (P = 0.01) influenced by the levels of soil moisture and soil fertility. The sums of squares of the two factors were 56.7% and 11.3% of the treatments sum of squares. It was also shown by the analysis that the linear and quadratic effects on seed yield for the stage of development at which the insects were infested to beans were highly significant at P = 0.01. Although the cubic effect for stage of development was also significant (P = 0.05), its sum of squares was only 3.9% of the total sum of squares due to the treatments imposed. The analysis further showed that only the effect on seed yield of the interaction between the stage of bean development and level of soil moisture was significant at P = 0.01, and its sum of squares was 5.5% of the treatment sum of squares. The effects on the number of seeds produced per plant of the interactions between the stage of bean development and level of fertility, levels of soil moisture and fertility, and of all the three factors were not significant at $P = 0.05$ (Table 20).

Comparison of the mean number of seeds produced per plant (Table 20) revealed that bean plants supplied with 10.0g DAP fertilizer, or watered at the level of 2.0ℓ per week produced significantly ($P = 0.01$) larger number of seeds than those grown without fertilizer, or watered at the level of 0.5ℓ per week, regardless of the stage of development at which *A. fabae* were infested onto the plants.

When beans were grown without fertilizer and supplied with 0.5ℓ of water per week, the plants attacked by the aphids at the early vegetative and late vegetative stages of development produced significantly ($P = 0.01$) different number of seeds when compared to each other and when compared to those attacked by the pest at the grain filling stage. Plants attacked by the aphids at the early vegetative stage also produced significantly ($P = 0.01$)

fewer seeds than those infested at the anthesis stage. However, seed yield of plants infested at the anthesis stage was not significantly ($P < 0.05$) different from those of plants attacked at the early vegetative, late vegetative, and anthesis stages of development (Table 20). At the watering level of 2.0ℓ per week, seed yield of plants attacked by *A. fabae* at the early vegetative, late vegetative and anthesis stages of development were significantly ($P = 0.01$) different from the control, but were not significantly different from each other at $P = 0.05$ (Table 20).

When 10.0g of DAP fertilizer were supplied to beans, the plants that received 0.5ℓ of water per week and attacked by *A. fabae* at the early vegetative, late vegetative and anthesis stages of development produced significantly ($P = 0.01$) fewer seeds than the control. Bean plants that were attacked by the aphids at the early vegetative stage also produced significantly ($P = 0.01$) fewer number of seeds than those attacked by the pest at the late vegetative, and anthesis stages of development. However, seed yield of plants infested with *A. fabae* at the anthesis stage was not significantly (P<0.05) different from those of plants attacked by aphids at the late vegetative and grain filling stages at P = 0.05 (Table 20). For bean plants that received 2.0ℓ of water per week, seed yield of plants infested with the aphids at the early vegetative and late vegetative stages were significantly (P = 0.01) different from each other and from those of plants that suffered infestation at the grain filling stages. Plants infested with A. fabae at the early vegetative stage also produced significantly (P = 0.01) fewer seeds than the control. However, the mean number of seeds produced by plants attacked by the pest at the anthesis stage was not significantly different from those of plants infested with the pest during the late vegetative and grain filling stages at P = 0.05 (Table 20).

The results obtained (Table 20) indicated that the levels of soil moisture and soil fertility and the stage of development at which A. fabae infested the plants were all important determinants of the number of seeds produced by bean plants. The level of soil moisture was however the single most important factor, since higher levels of soil moisture improved plant response to soil fertility,

Table 20: The means and analysis of variance of the number of seeds produced per plant by beans grown using two levels of soil moisture and soil fertility and infested with A. fabae at four stages of plant development.

a) analysis of variance of number of seeds per plant.

source of variation	df	SS	MS	F
total	95	55615.13		
stage of bean development (S)	(3)	11063.04		
linear	1	9091.50	9091.50	90.10**
quadratic	1	1544.01	1544.01	15.30**
cubic	1	427.52	427.52	4.24*
level of soil fertility (F)	1	5355.10	5355.10	53.07**
level of soil moisture (M)	1	26967.51	26967.51	267.26**
interaction S x F	3	839.28	279.76	2.76
interaction S x M	3	2612.02	870.76	8.63**
interaction F x M	1	446.34	148.78	1.47
interaction F x M x S	3	259.70	86.57	0.86
error	80	8072.14	100.90	

significant: *P = 0.05; **P = 0.01 CV -25.44%
SE stage means =20.50; SE fertility and moisture means = 1.450.

b) mean number of seeds produced per plant

level of fertility	level of moisture	stage of bean development			
		early vegetative	late vegetative	anthesis	grain filling
0.0g	0.5ℓ	9.83a	16.17b	20.01bc	23.33c
	2.0ℓ	39.17a	39.50a	41.00a	66.50b
10.0g	0.5ℓ	20.51a	23.35ab	28.31b	40.83c
	2.0ℓ	48.12a	56.50b	58.67bc	99.83c

LSD between (fertility, and moisture) means 0.05 = 4.10
0.01 = 5.46

a,b,c: for each level of soil moisture, means denoted by the same letter are not significantly (P = 0.05) different (Duncan's New Multiple Range test).

increased seed yield, and dampened the effects of aphid infestation. *A. fabae* attack at the early vegetative, late vegetative and anthesis stages of development were shown to be the most harmful to the plants as already shown in earlier observations.

The weight of seeds produced per plant as influenced by the levels of soil moisture and soil fertility and by the stage of bean development at which *A. fabae* were infested to the plants is given in Table 21. The mean weight of seeds produced per plant (Table 21) showed that the higher levels of soil fertility and soil moisture resulted in greater seed yield of beans. The weight of seeds produced was substantially reduced when the aphids attacked bean plants at the early vegetative, late vegetative and anthesis stages of development. However the reduction in yield was most severe on plants when aphids were introduced onto them during the early vegetative and late vegetative stages.

The analysis of variance (Table 21) showed that the influence of the levels of soil moisture and soil fertility on the weight of seeds produced per plant were highly significant at $P = 0.01$. The two treatments accounted for 57.6% and 11.0% respectively of the total sum of squares due to the treatments imposed on beans. The analysis also showed significant ($P \geq 0.05$) linear and quadratic effects on seed yield for the stage of development at which the aphids were infested to the plants. The cubic effect for stage of development was not significant at P = 0.05. The sum of squares for the stage of development was 23.8% of the treatment sum of squares It was also shown by the analysis that only the effect on seed weight of the interaction between stage of bean development and level of soil moisture, was significant at P = 0.01, and its sum of squares was 4.5% of the treatment sum of squares. The effects of the interactions between the stage of development and level of soil fertility, levels of soil moisture and fertility, and of all three factors on the yield of seeds were not significant at P = 0.05 (Table 21). Their respective sums of squares were only 1.7%, 1.1% and 0.5% of the total sums of squares due to the treatments imposed.

The comparison of the mean weight of seeds produced per plant (Table 21) revealed that the weight of seeds produced by plants watered at the level of 2.0ℓ per weekand supplied with 10.0g of DAP fertilizer was significantly (P = 0.01) greater than those of plants watered at the level of 0.5ℓ per week and grown without fertilizer, irrespective of the stage of development at which the aphids were infested to them.

When beans grown without DAP fertilizer and supplied with 0.5ℓ of water per week were infested with four *A. fabae* each, plants attacked by the aphids at the early vegetative and late vegetative stages of development produced a significantly (P = 0.01) smaller weight of seeds than those of the control. The weight of seeds of plants infested with the pest at the early vegetative stage was also significantly (P = 0.01) smaller than those of plants attacked at the anthesis stage, but was not significantly (P<0.05) different from those of plants infested at the late vegetative stage of development. When the aphids were introduced onto the plants at the anthesis stage, the weight of seeds produced was not significantly (P<0.05) different from those of plants attacked by the insects at the late vegetative and grain filling stages (Table 21). For the plants supplied with 2.0ℓ of water per week, the mean weight of seeds produced by plants when aphid attack occurred at the early vegetative, late vegetative and anthesis stages were significantly (P = 0.01) different from each other and from the control.

When beans were raised using 10.0g of fertilizer however, for both levels of soil moisture, the weight of seeds produced by plants attacked by *A. fabae* at the early vegetative, late vegetative and anthesis stages of development were significantly (P = 0.01) different from that of plants infested at the grain filling stage. The weight of seeds produced by plants that suffered aphid attack at the early vegetative and late vegetative stages were also significantly (P = 0.01) different from those of plants infested at the anthesis stage, but were not significantly different from each other at P = 0.05 (Table 21).

These results presented in Table 21 clearly indicated that seed yield of beans was greatly influenced by all the treatments applied to the plants. It was also shown that low levels of soil moisture and soil fertility severely reduced the productivity of beans and increased the influence on seed yield of plant damage due to *A. fabae* attack.

Table 21: The means and analysis of variance of the weight (gm) of seeds produced per plant by plants grown using two levels of soil moisture and soil fertility and infested with A. fabae at four stages of devevclopment.

a) analysis of variance of weight (gm) of seeds per plant.

source of variation	df	SS	MS	F
total	95	5491.05		
stage of bean development (S)	(3)	1107.02		
linear	1	1047.49	1047.49	100.53**
quadratic	1	56.98	56.98	5.47*
cubic	1	2.55	2.55	0.24
level of soil fertility (F)	1	511.16	511.16	49.05**
level of soil moisture (M)	1	2682.03	2682.03	257.35**
interaction S x F	3	78.40	26.13	2.51
interaction S x M	3	207.65	69.22	6.64**
interaction F x M	1	50.08	50.08	4.81**
interaction F x M x S	3	20.99	7.00	0.67
error	80	833.72	10.42	

CV = 28.68%

significant * at P = 0.05; ** at P = 0.01;
SE stage mean = 0.659 gm; SE fertility or moisture mean = 0.466 gm.

b) mean weight (gm) of seeds produced per plant

level of fertility	level of moisture	stage of plant development			
		early vegetative	late vegetative	anthesis	grain filling
0.0g	0.5ℓ	1.92a	3.94ab	5.20bc	6.44c
	2.0ℓ	8.87a	11.29b	14.87c	18.93d
10.0g	0.5ℓ	4.90a	6.07a	8.13b	11.13c
	2.0ℓ	14.26a	15.62a	18.79b	29.62c

LSD between (fertility or moisture) means 0.05 = 1.32 gm
0.01 = 1.75 gm

a,b,c,d: for each level of soil moisture, means denoted by the same letter are not significantly (P = 0.05) different (Duncan's New Multiple Range test).

The means obtained from these studies for the different parameters of growth, reproduction and yield of beans raised using two levels of soil moisture and soil fertility and infested with four *A. fabae* per plant at the various stages of development are summarised in Appendix Table V. The summary for the analyses of variance of the various plant characters assessed is also given in Appendix Table VI.

The studies of bean damage by aphids in terms of plant growth, reproduction and yield therefore clearly indicated that the low levels of soil moisture and soil fertility severely reduced the productivity of beans and increased the effects of *A. fabae* attack. The results further indicated that aphid attack was most damaging when infestation occurred at the early vegetative, late vegetative and anthesis stages of development. Damage on plants infested after the flowering stage was minimal.

4:4 DISCUSSION

In the present studies it was observed that *A. fabae* infested to beans during the early and late vegetative stages of development developed large populations within two to three weeks, whereas over a similar period only small populations developed on bean plants infested at the anthesis and grain-filling stages. This was in conformity with previous observations that *A. fabae* developed and multiplied more on young rapidly growing plants than on old mature ones (Ibbotson and Kennedy, 1951; Kennedy and Booth, 1950, 1954).

Observations during the current studies also showed that damage to bean growth and yield was severe on plants which were attacked by aphids during the early and late vegetative stages of development, but was mild or minor on plants infested with the pest during and after the flowering stage of development. This could be explained by the fact that during the pre-flowring stages, the plants were still young, their tissues tender, succulent and nutritive to aphids, which resulted in the build-up of damaging *A. fabae* populations. It was also considered that during these stages of rapid plant growth, the young tender plants were more responsive to aphid damage than the older ones. During anthesis and grain filling stages, bean growth had virtually ceased, and the plant tissues were old, non-succulent and less nutritive to the insects. As such fewer individuals of the bean aphid were produced on these plants, and given that the plants were old and hardy, the pests caused only minor damage to them.

In these studies, A. fabae attack on common beans has been shown to cause serious reduction in the growth of shoots, the number of flowers per plant, pods per plant, seeds per plant and the weight of seeds per plant. Similar observations of A. fabae damage to field beans V. faba were reported by Judenko et. al. (1952) and Way et. al. (1954). It has been established that bean yields are governed by the number of pods per plant (Sinha, 1974; Sinha and Savithri, 1978; Adams, 1967; Duarte and Adams, 1972; Ishag, 1973). Therefore the loss in the quantity of pods as a result of A. fabae attack on beans during the vegetative and anthesis stages of development accounted for the reduction in seed yields of these plants.

It was also shown in these studies that the higher levels of A. fabae infestation resulted in greater damage to beans. This was probably due to the fact that larger aphid populations which were observed to develop in a shorter time from higher levels of initial infestations caused comparatively greater damage than the smaller populations which developed from low levels of initial infestations. Similar observations have been reported by Davidson (1925), Ingram (1969) and Barlow (1973).

Data obtained during the present studies also showed that only plants infested with virus-carrying aphids during the pre-flowering stages of development developed symptoms of CBMV whereas those attacked during the anthesis and grain filling stages remained apparently free of the disease. Similar pattern of CBMV infectivity have been reported by Bos (1971) and Nelson, cited by Smith (1972). It was also observed that aphid transmission of the virus was independent of the level of A. fabae infestation. This can be explained by the fact that CBMV is mechanically transmitted and is translocated within the plant and therefore successful penetration of the plant tissue by a single virus-carrying aphid can lead to the transmission of the disease (Bos, 1971; Smith, 1972; Watson, 1967).

Because of the close parasitic dependence of aphids on very variable host plants, it has been considered that the conditions of the host plants is particularly important in aphid-host interactions Kennedy, 1958; Kennedy and Stroyan 1959; Waghray and Singh, 1965; Wearing and van Emden, 1967; Kindler and Stapples, 1970). Results obtained in the present studies revealed that levels of soil moisture and fertility influenced plant growth and compounded the effects of _A. fabae_ attack on common beans. These observations also showed that the level of soil moisture was particularly important as it influenced the response of beans to soil fertility and aphid attack. In previous studies similar responses were observed under field conditions (Soper, 1952).

From the studies presented here, the effects of _A. fabae_ attack and virus transmission were clearly shown to be dependent on the stage of bean development. It was also demonstrated that the extent of aphid damage to bean plants was governed by the conditions of growth of plants being infested by the pests. It was therefore concluded that the control of _A. fabae_ damage to beans must of necessity be based on consideration of the stage of plant development, level of aphid infestation and the conditions of growth of the plants being attacked.

CHAPTER 5

STUDIES ON THE FIELD INCIDENCE OF THE BEAN APHID A. FABAE AND THE PERFORMANCE OF THE APHID ON TEN VARIETIES OF COMMON BEANS P. VULGARIS UNDER GREENHOUSE CONDITIONS.

5:1 INTRODUCTION.

Previous observations have indicated that there is a fairly consistent pattern of aphid population densities throughout the year in the highland regions of Kenya (Eastop, 1957; Kulkarni, 1972). These workers observed that aphid populations were low from February to April and increased markedly in June and July. The relationship of this population pattern to the incidence of A. fabae on common beans has not been investigated.

However, it has been observed that common bean crops planted late in the first rains in this country tend to suffer more severe attacks from the aphid than those planted early in the season at the onset of rains (Schonherr and Mbugua, 1976). These observations indicated that the incidence of the aphids on common beans was partly determined by the time of planting of the crop.

Knowledge on the seasonal incidence of A. fabae on common beans would be essential in designing control strategies for the pest, and for this reason part of the studies reported here were conducted to obtain this information.

The biological performance of *A. fabae* have been shown to vary on plants of different varieties of field beans (Davidson, 1925; Muller, 1958; Tambs-Lyche and Kennedy, 1958; Banks and Macaulay, 1970) and of common beans (Steinmetz and Amy, 1932; McKinney, 1938). Painter (1951) showed that biological abnormalities occurred when insects fed on plants possessing antiobiotic resistance, and this has been used as a basis for testing for resistance to *A. fabae* in field beans (Bond and Lowe, 1975).

As part of the studies reported here, the biological performance of *A. fabae* on ten major varieties of common beans grown in Kenya was assessed. It was hoped that aphid performance on these varieties would give some indication of the presence and extent of their resistance to the pest. This could serve as an important starting point for the development of common bean varieties resistant to aphids.

5:2 MATERIALS AND METHODS

5:2:1 General procedure.

Field and greenhouse experiments were conducted at the University Farm, Field Station, Kabete Campus during 1981 and 1982. The ten varieties of common beans used in these studies were: Mwezi Moja (GLP. 10), Red Haricot (GLP.3), Red Rose Coco (GLP.2), White Haricot (M.142), Canadian Wonder (GLP.25), Small White Rose Coco (GLP. 1), Large White Rose Coco (NBI.1401), Pink Rose Coco (GLP. 1128), Zebra Bean (Fs.520), and Mwitemania (GLP. 92).

For field studies, bean seeds were dressed with Aldrin 40% WP before planting to minimise seedling damage by the bean fly Ophiomyia phaseoli (Tyron) (= Melanagromyza phaseoli (Tyron)). The seeds were planted three per hole and the seedlings thinned to leave one plant per hole one week after emergence. The spacing used was 50 cm between the rows and the seeds were planted 20 cm apart within the row. The plots were kept free of weeds.

Bean plants used in the greenhouse studies were raised following general procedures described in earlier experiments in Chapter 3. The test plants were grown in brown sand soil, and 50 mls. of a solution of 5.0g of NPK (20:20: 20) fertilizer in one litre of water was added to each pot every week. The plants were thinned one week after emergence, and uniformly growing plants were left in each pot.

The *A. fabae* used to infest plants in these studies were also obtained from colonies raised using the "production line" method of Kennedy and Booth (1950) as described in earlier experiments in Chapter 3.

5:2:2 Field studies of the seasonal incidence of the bean aphid *A. fabae* on common beans *P. vulgaris* at Kabete, 1981-1982.

The purpose of these experiments was to evaluate the incidence of *A. fabae* on bean crops planted at different times of the year. This is important in relating the level of aphid attack and bean crop damage to the time of planting of beans in the field. Bean crops were therefore planted in the field on the following dates: 9th November, 1981; 15th January 1982, 6th April 1982, and 21st June 1982.

The bean varieties Mwezi Moja, Red Haricot, Red Rose Coco and Small White Rose Coco were each planted in six 7m long rows in 12 x 7 m plots that were replicated four times. The crops planted in November 1981 and January 1982 were regularly irrigated to boost their growth since rains received were not sufficient.

Sampling started three days after the plants had been thinned and was carried out at weekly intervals for three weeks. The sampling was limited to four weeks of bean growth in order to assess primary migrations only. After this period of infestation winged aphid migrants from the colonies on the plants usually cause secondary infestation on plants (Way _et. al_., 1954; Johnson _et. al_., 1957 b; Cockbain _et. al_., 1963).

At each sampling occasion, two rows of each of the varieties of beans in each replicate were randomly selected. All the plants in these rows were counted and examined to record the numbers which were infested and those which were not infested by aphid colonies.

5:2:3 The field incidence of *A. fabae* on ten varieties of common beans *P. vulgaris* at Kabete.

The aim of this experiment was to assess the incidence and development of *A. fabae* infestation on the different varieties of common beans when grown in the field. It was felt that aphid infestation on these varieties would indicate either the relative attractiveness of the varieties to aphids or their relative suitability for aphid colonisation in the field. This aphid-host relationship would provide preliminary information useful in the investigation of aphid resistance in these varieties.

Bean crops were planted in the field on 15th May 1982. The ten varieties of beans were planted in plots that measured 10 x 7 m and replicated four times. Each variety was randomly planted in each plot in two rows 7 m long.

Sampling commenced three days after the plants had been thinned and was conducted at intervals of one week for four weeks. One row of each bean variety was selected from every replicate and all the plants in it counted and examined to record the number of plants that were infested and those that were not infested by aphid colonies.

5:2:4 Studies of the "developmental period" and nymphal mortality of the bean aphids *A. fabae* fed on ten varieties of common beans *P. vulgaris* in the greenhouse.

The purpose of these experiments was to assess the influence on aphid development of the different varieties of beans on which *A. fabae* was reared. Differences in aphid development and nymphal mortality would serve to indicate the suitability of the various varieties to the aphids, and hence their possible resistance or susceptibility to the pest.

For each of the ten varieties of beans used, three pots (diameter 20 cm) each containing two uniformly growing plants were selected four days after the plants had been thinned, and two freshly moulted *A. fabae* adults infested to each plant. The aphids were allowed to reproduce for three hours after which only five of the nymphs born were left on each plant. The rest of the nymphs produced and their adult mother aphids were removed. This ensured that the *A. fabae* nymphs remaining on the seedlings were of the same age. The aphids were then left to grow and develop on the plants.

Everyday the nymphs were examined three times at 8.00 a.m., 12.00 noon, and 5.00 p.m. and the number of those that moulted or died recorded. This observation was continued until the nymphs started producing young ones. Each aphid that began larviposition was removed from the plants and the approximate time of first larviposition recorded.

5:2:5 Studies of the development of *A. fabae* populations on ten different varieties of common beans *P. vulgaris* under greenhouse conditions.

The experiment was carried out in order to assess the build-up of *A. fabae* populations on ten varieties of common beans when the aphid was infested to them at the level of two individuals per plant. It was not known how the different varieties of beans influenced the build-up of *A. fabae* populations infesting them. This knowledge would give an indication on the biological performance of the aphids on the different varieties of beans.

For each variety of beans, eight pots (diameter 20 cm) each containing three uniformly growing plants were selected four days after the plants had been thinned. Two freshly moulted *A fabae* adults were infested to each plant and then left to reproduce.

The aphids on the plants were counted eight times at intervals of two days, beginning two days after the start of larviposition. At each day of counting, one pot was randomly removed for each variety and the number of aphids on each plant counted. This experiment was conducted two times.

5:3 RESULTS

5:3:1 The seasonal incidence of the bean aphid *A. fabae* on common beans *P. vulgaris* at Kabete, 1981-1982.

The observations on the incidence of *A. fabae* on common beans planted at four different times of the year are presented in Figure 7. These observations (Fig. 7) showed that *A. fabae* infestation on common beans in the field varied enormously, depending on the time of year at which the crops were planted. The rate of progress of infestation also varied on crops planted at different periods of the year. Aphid infestation on beans was largest on crops planted in June 1982, and smallest on crops planted in January, 1982. Furthermore, the build-up of infestation was most rapid on bean crops cultivated in June 1982, and slowest on crops grown in January 1982.

The observations, Figure 7, showed that crops planted towards the end of the short rains in November 1981 had a relatively high incidence of *A. fabae* infestation. Four weeks after emergence, upto 39.3% of the plants sampled possessed aphid colonies. The build-up of infestation on this crop was slow in the first three weeks after plant emergence. However the proportion of plants infested with aphids rose rapidly in the fourth week.

When bean crops were planted during the long dry season in January 1982, the plants suffered virtually no aphid attack, and only 1.3% of the plants possessed aphid colonies five weeks after planting.

The incidence of aphid attack on beans was also low on crops planted at the start of the long rains in April 1982. The proportion of plants infested with aphids after four weeks of growth was only 13.0% of the plants sampled. The build-up of infestation was also slow, particularly during the first three weeks after plant emergence (Figure 7).

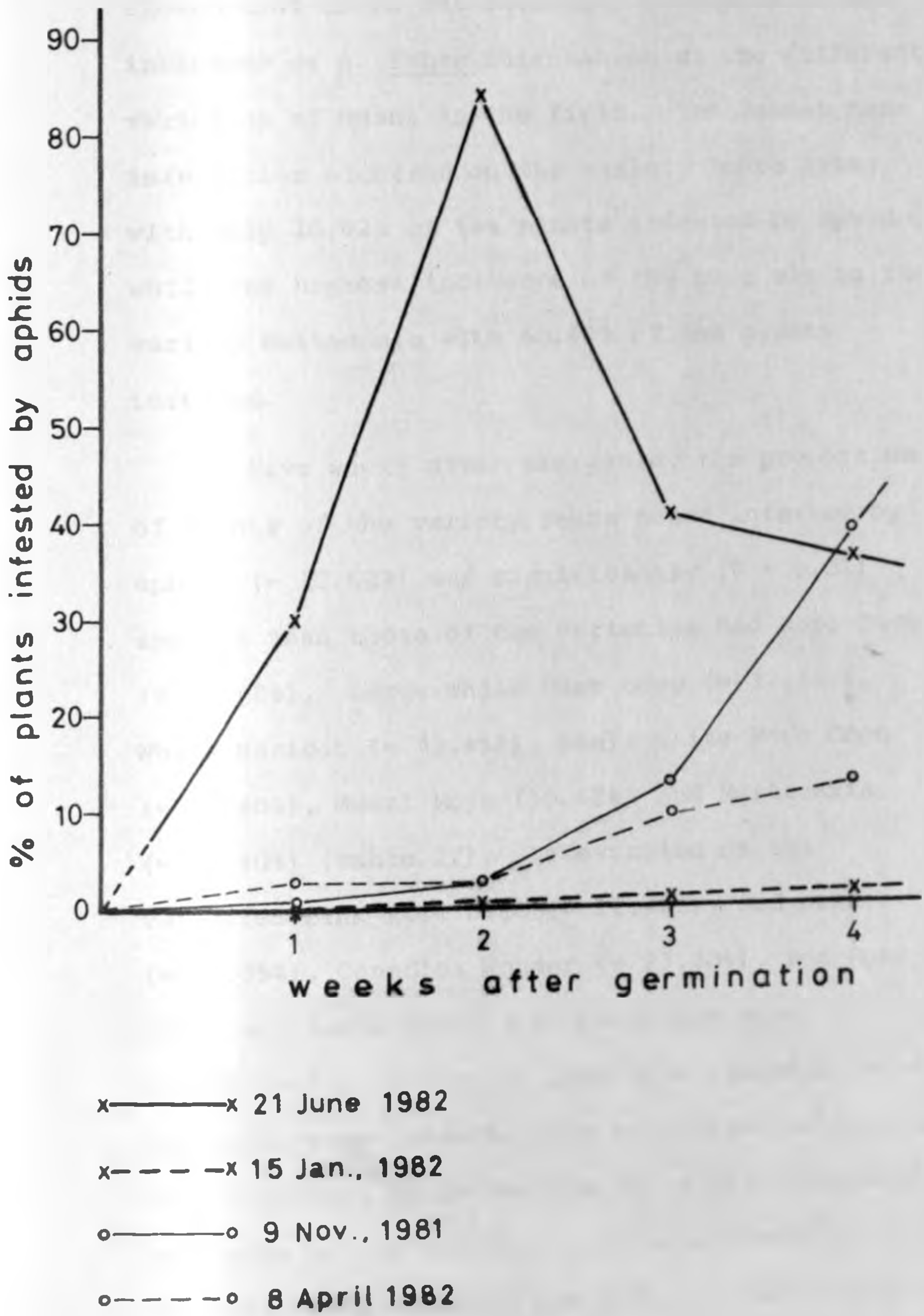
When bean crops were planted towards the end of the long rains in June 1982, aphid infestation of the plants was particularly high, and upto 84.8% of the plants were infested by aphids three weeks after emergence. The rate of infestation was also very rapid in the first three weeks of bean growth (Figure 7). However, the proportion of plants that carried aphid colonies dropped suddenly following several days of rain four weeks after planting. Because of this, only 35.8% of the plants possessed aphid colonies one week later (Figure 7).

It was indicated by the observations obtained during these studies that bean crops grown early at the start of the long rains in April could mature before serious infestations of *A. fabae* developed and thus escape damage from aphid attack. However, crops planted late after the main cultivation could suffer heavy aphid attack arising from secondary infestations that develop on crops planted early at the start of the season. It is likely therefore that most cases of severe aphid damage arise as a result of delayed cultivation of beans after the onset of rains.

5:3:2 The field incidence of *A. fabae* on ten varieties of common beans *P. vulgaris* at Kabete.

The percentage of plants infested by aphids five weeks after emergence when the ten varieties of common beans were grown in the field is given in Table 22. These results (Table 22)

Fig. 7. The incidence of A. fabae infestation on bean crop planted at four different periods of the year.



showed that there was extensive variation in the incidence of A. fabae infestation on the different varieties of beans in the field. The lowest mean infestation occurred on the variety Zebra Beans, with only 10.62% of the plants infested by aphids, while the highest incidence of the pest was on the variety Mwitemania with 60.40% of the plants infested.

Five weeks after emergence, the proportion of plants of the variety Zebra Beans infested by aphids (= 10.63%) was significantly (P = 0.01) smaller than those of the varieties Red Rose Coco (= 34.48%), Large White Rose Coco (= 37.56%), White Haricot (= 42.45%), Small White Rose Coco (= 48.40%), Mwezi Moja (50.48%) and Mwitemania (= 60.40%) (Table 22). Infestation on the varieties Pink Rose Coco (= 22.42%), Red Haricot (= 23.35%), Canadian Wonder (= 23.60%), Red Rose Coco and Large White Rose Coco were also significantly (P = 0.01) less than infestation on the variety Mwitemania. The proportion of plants of the variety White Haricot (= 42.45%) attacked by aphids in the field was not significantly different from those of the other varieties except

Zebra Beans, at the level of P = 0.01 (Table 22).

The development of aphid infestation on bean crops during the first five weeks of plant growth on five representative varieties is shown in Figure 8. Except for the variety Mwitemania, A. fabae incidence in the first three weeks of growth was low and similar on all the varieties assessed. Infestation on Mwitemania was consistently higher than on the rest of the varieties, showing that it was the most susceptible variety. On the other hand aphid infestation was lowest on the variety Canadian Wonder throughout the five weeks of plant growth, indicating that the variety was the most resistant to the aphids.

The results obtained in these studies showed that A. fabae incidence in the field varied on the different varieties of beans tested. This indicated that the bean varieties possessed varying levels of resistance to the pest.

5:3:3 The "developmental period" and nymphal mortality of the bean aphid A. fabae when fed on ten varieties of common beans.

The mean duration of the "developmental

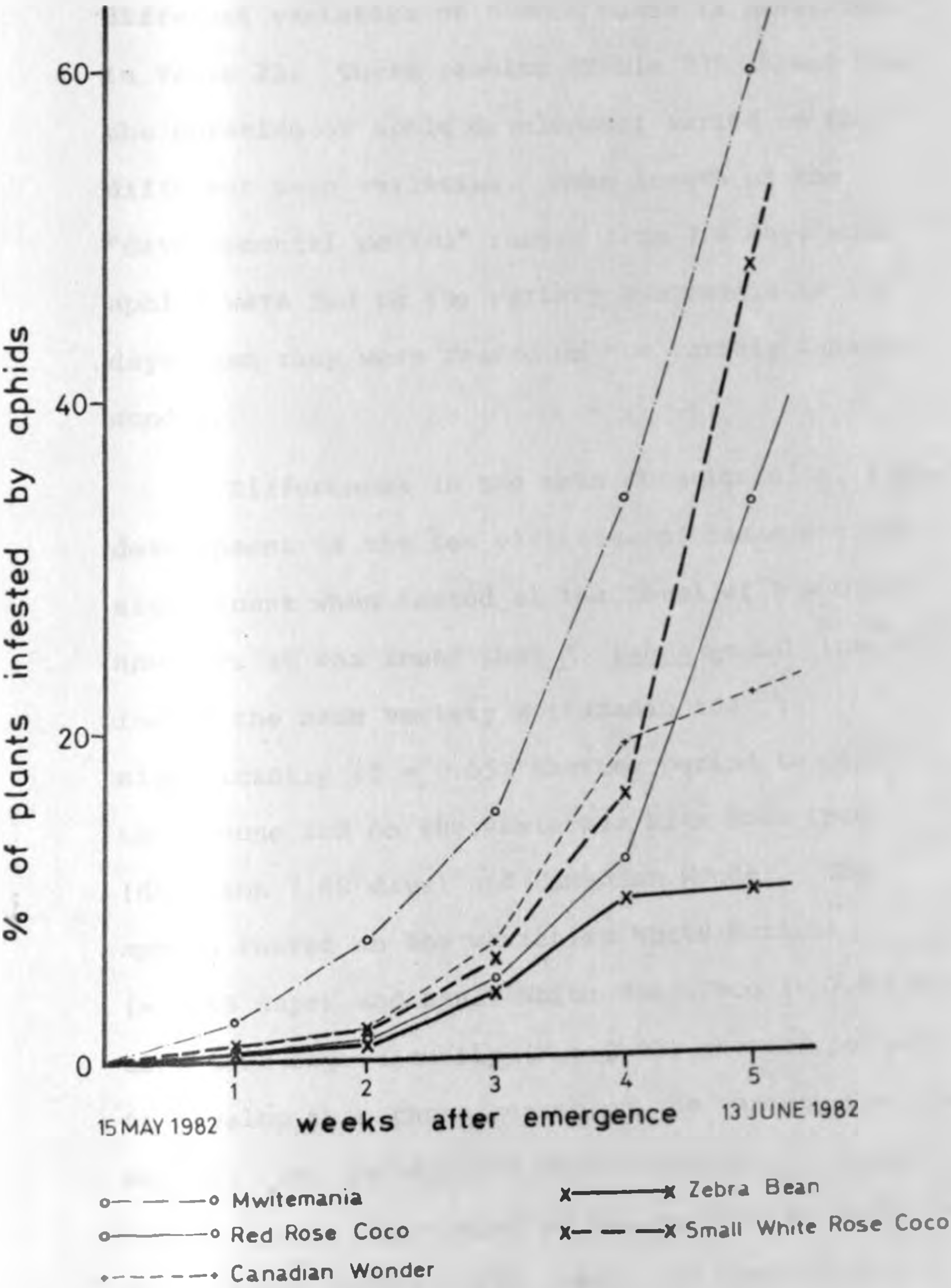
Table 22: The percentage of bean plants infested by _A. fabae_ sampled five weeks after emergence for ten varieties of common beans _P. vulgaris_ grown in the field.

bean varieties	no. plants sampled (4 replicates)	no. plants infested with aphids	percentage infestation
Zebra Bean	141	15	10.62 a
Pink Rose Coco	142	32	22.43 ab
Red Haricot	142	33	23.35 ab
Canadian Wonder	144	34	23.60 ab
Red Rose Coco	142	49	34.48 bc
Large Rose Coco	141	53	37.56 bc
White Haricot	144	61	42.45 bcd
Small Rose Coco	143	69	48.40 cd
Mwezi Moja	141	71	50.48 cd
Mwitemani	144	87	60.40 d

Coefficient of variation = 28.74%

a,b,c,: percentages denoted by the same letter are not significant different at the level of P = 0.01 (Duncan's New Multiple Range Test)

Fig. 8. The build-up of *A. fabae* infestation on five varieties of common beans in the field.



period" of a *A. fabae* when fed on seedlings of the different varieties of common beans is presented in Table 23. These results (Table 23) showed that the duration of aphid development varied on the different bean varieties. Mean length of the "developmental period" ranged from 7.6 days when aphids were fed on the variety Mwetemania to 7.9 days when they were reared on the variety Canadian Wonder.

Differences in the mean duration of *A. fabae* development on the ten varieties of beans was not significant when tested at the level of P = 0.01. However, it was found that *A. fabae* nymphal instars fed on the bean variety Mwitemania took a significantly (P = 0.05) shorter period to develop than those fed on the varieties Pink Rose Coco (duration 7.88 days) and Canadian Wonder. The aphids reared on the varieties White Haricot (= 7.65 days) and Small White Rose Coco (= 7.65 days) also took significantly (P = 0.05) shorter periods to develop than those reared on the variety Canadian Wonder. The duration of development of *A. fabae* nymphs fed on the varieties Red Haricot (= 7.75 days) Mwezi Moja (= 7.78 days), Red Rose Coco

(= 7.83 days), Large White Rose Coco (= 7.85 days) and Zebra Beans (= 7.86 days), was not significant ($P < 0.05$) when compared to each other and when compared to the length of development of nymphs fed on the varieties Canadian Wonder, Pink Rose Coco, White Haricot, Small White Rose Coco and Mwitemania (Table 23).

The results of these studies presented in Table 23 showed that A. fabae nymphs developed most rapidly on Mwitemania, White Haricot and Small White Rose Coco varieties of common beans, while they took considerably longer periods to develop when fed on the varieties Canadian Wonder and Pink Rose Coco. This indicated that the later varieties of beans were less suitable for aphid development than the first three since aphid development was apparently most adversely affected for aphids reared on them.

The percentage mortality of A. fabae nymphs on bean plants of the different varieties analysed after transformation using arc sin $\sqrt{n + 0.5}$ percentage transformation (Raimer, 1959; Southwood, 1966; Steel and Torrie 1980), is given in Table 24. The results presented in Table 24 showed that nymphal

Table 23: The mean duration in days of the "developmental period" of *A. fabae* when reared on ten varieties of common beans *P. vulgaris* in the greenhouse.

bean varieties	(code)	mean duration of "developmental period"
Mwitemania	GLP.92	7.60a
Small White Rose Coco	GLP.1	7.65ab
White Haricot	M.142	7.65ab
Red Haricot	GLP.3	7.75abc
Mwezi Moja	GLP.10	7.78abc
Red Rose Coco	GLP.2	7.83abc
Large White Rose Coco	NB1.1401	7.85abc
Zebra Bean	FS.520	7.86abc
Pink Rose Coco	GLP.1128	7.88bc
Canadian Wonder	GLP.25	7.90c

standard error of mean = 0.08 days

coefficient of variation = 3.17%

a,b,c,:means denoted by the same letter are not significantly different at the level of P = 0.05 (Duncan's (1955). New Multiple Range test).

mortality varied between the different varieties of beans on which the aphids were raised. The highest nymphal mortality occurred on the variety Canadian Wonder, with a mean of seven out of every fifteen nymphs dying during development, while the lowest mortality was recorded on the variety Mwitemania with only one out of every fifteen nymphs dying before maturity.

The analysis of data Table 24, showed that when *A. fabae* nymphs were raised on the bean variety Mwitemania, significantly (P = 0.01) fewer nymphs died (= 6.7%) during development than when the aphids were reared on the varieties Mwezi Moja (= 33.3%), Zebra Beans (= 37.8%), Red Haricot (= 40.0%), Pink Rose Coco (= 40.0%), and Canadian Wonder (= 46.6%),(Table 24). It was further observed that significantly (P = 0.01) fewer nymphs died when the aphids were raised on the variety Small White Rose Coco (= 15.5%) than on the variety Canadian Wonder. However, nymphal mortalities when *A. fabae* were fed on the varieties Red Rose Coco (= 20.0%), White Haricot (= 22.2%), Large White Rose Coco (= 26.7%), Mwezi Moja (=33.3%), Zebra Beans (=37.8%), Red Haricot (=40.0%),and Pink

Rose Coco (= 40.0%) were not significant (P<0.05) when compared to each other and when compared to mortalities on the varieties Canadian Wonder (= 46.6%), Small White Rosa Coco (=15.7%) and Mwitemania (= 6.7%) (Table 24).

The results presented in Table 24 showed that the mortality of nymphal instars of A. fabae varied when the aphids fed on different varieties of beans. This indicated that resistance to the aphid is present at varied levels amongst the bean varieties tested, with the varieties Canadian Wonder, Red Haricot and Pink Rose Coco possessing the highest levels of resistance.

5:3:4 The development of A. fabae populations on ten varieties of common beans P. vulgaris in the greenhouse.

The number of progenies produced when A. fabae infested to bean seedlings at the level of two individuals per plant were left to reproduce for 16 days on ten varieties of common beans is presented in Table 25. These results (Table 25) showed that the total number of progenies produced by the aphids varied between the ten varieties of

Table 24: The percentage of nymphs dying when A. *fabae* nymphs were reared to maturity on ten varieties of common beans P. *vulgaris* in the greenhouse.

bean varieties	No. nymphs introduced	no. dead after 8 days	percentage mortality
Mwitemania	45	3	6.7 a
Small Rose Coco	45	7	15.7 ab
Red Rose Coco	45	9	20.0 abc
White Haricot	45	10	22.2 abc
Large Rose Coco	45	12	26.7 abc
Mwezi Moja	45	15	33.3 bc
Zebra Bean	45	17	37.8 bc
Red Haricot	45	18	40.0 bc
Pink Rose Coco	45	18	40.0 bc
Canadian Wonder	45	21	46.6 c

Coefficient of variation = 28.74%

a, b, c: percentages denoted by the same letter are not significantly different at the level of $P = 0.01$ (Duncan's New Multiple Range Test).

beans tested. After 16 days of reproduction, the mean number of *A. fabae* on each bean plant ranged from 172.4 nymphs on Zebra Beans to 272.8 nymphs on the variety Mwitemania.

It was found that the mean number of progenies of *A. fabae* obtained after 16 days of reproduction on the bean varieties Zebra Bean (= 172.4 nymphs), Pink Rose Coco (= 176.4 nymphs), Canadian Wonder (= 180.3 nymphs), Red Haricot (= 195.1 nymphs), and White Haricot (= 195.5 nymphs) were significantly (P = 0.01) fewer than when the aphids were reared on the varieties Mwitemania (= 272.8 nymphs), and Small White Rose Coco (= 247.3 nymphs), but were not significantly different from each other at the level of P = 0.01 (Table 25). The results further showed that the mean number of progenies of the aphids when reared on the varieties Red Rose Coco (= 214.5 nymphs), Mwezi Moja (= 227.6 nymphs) and Large White Rose Coco (= 237.9 nymphs) were not significantly (P = <0.01) different from each other and from those obtained on the other seven varieties compared above.

The results presented in Table 25 indicated that the bean varieties Zebra Beans, Pink Rose Coco,

Table 25: The number of progenies obtained per plant when *A. fabae* infested to ten varieties of common beans at the level of two adults per plant were left to reproduce for 16 days in the greenhouse.

bean varieties	replicates I	II	III	means
Zebra Bean	175.1	163.3	178.8	172.4a
Pink Rose Coco	177.3	192.7	159.2	176.4a
Canadian Wonder	176.7	180.9	183.7	180.3a
Red Haricot	192.3	179.2	213.9	195.1ab
White Haricot	230.3	196.5	159.7	195.5ab
Red Rose Coco	199.3	230.3	213.9	214.5abc
Mwezi Moja	243.5	199.7	239.3	227.6abc
Large Rose Coco	189.5	292.6	231.7	237.9abc
Small Rose Coco	257.3	223.5	261.2	247.3bc
Mwitemania	287.7	271.4	259.3	273.8c

standard error of mean = 14.10

coefficient of variation = 11.52%

a,b,c: means denoted by the same letter are not significantly different at the level of P = 0.01 (Duncan's (1955) New Multiple Range test).

Canadian Wonder and Red Haricot possessed the greatest resistance to *A. fabae* whereas the varieties Mwitemania and Small White Rose Coco possessed the least resistance to the pest.

From the studies of *A. fabae* performances on the ten varieties of beans, it was generally observed that plant influence and *A. fabae* responses varied between the various bean varieties. The biological performance of the aphid was generally better on the varieties Mwitemania, Small White Rose Coco, Mwezi Moja, Large White Rose Coco and White Haricot, indicating that these varieties were the most suitable as hosts of the pest. In contrast, aphid performance was generally poor on the varieties Zebra Bean, Pink Rose Coco, Canadian Wonder, Red Haricot and Red Rose Coco, and aphids took longer to develop, died more or reproduced less on them than on the other varieties. Varied potential for the development of resistance to aphids is therefore indicated for the ten varieties of beans tested.

5:4 DISCUSSION

It has been stated that certain inherent characteristics of plants may strongly influence the biological relationship between them and their insect pests (Painter, 1951, 1958; Howe and Smith, 1957; Johnson, 1953; Beck, 1965; Horber, 1972). This perhaps partly account for the wide variations in the duration of nymphal development, mortality and build-up of populations when *A. fabae* were reared on seedlings of ten different varieties of beans. The bean aphid *A. fabae* performed poorly on several varieties namely Canadian Wonder, Pink Rose Coco and Zebra Beans. Because of this these varieties were regarded as being resistant to the aphids.

The field incidence of *A. fabae* on the ten varieties of common beans did not exactly correspond to the pattern of their population development on these varieties in the greenhouse. These observations indicated that besides the plant factors, other factors which were not immediately established prevailed under field conditions and partly influenced aphid establishment and survival on bean hosts.

From these investigations, differences in bean influences and *A. fabae* responses were shown by the various varieties of beans tested, and varied potential for the development of varieties of beans resistant to the aphid was indicated. The advantage of early planting of bean crops in minimising *A. fabae* attack on them was clearly demonstrated and if incorporated in cropping plans, it could substantially reduce bean yield losses due to aphid pests.

CHAPTER 6

GENERAL DISCUSSION AND CONCLUSIONS

Studies reported in this thesis were based on the need to develop an integrated approach to the management of A. fabae and other pests of legumes. This need was amplified in Chapter 1. The desirability of a multiple factor approach to pest management and control as a basis for minimising environmental degradation and risk of pesticide resistance among pests have been emphasised (Khaemba, 1980; Singh and van Emden, 1979; Bond and Lowe, 1975; Ingram, 1969; Way, 1961, 1967; Anon. 1979 b).

A. fabae is known to be a sporadic but serious pest of beans and other legumes in the tropics, and it is known to transmit over 30 virus diseases (Hill, 1975). Because of the dynamic nature of aphid pest problems various control strategies must be taken into consideration in order to ensure that economic losses do not arise from A. fabae attack on common beans. An invaluable first step in minimising aphid damage is the utilisation of sound cultural practices. It has been demonstrated in the present studies that early planting and the use of adequate levels of soil moisture and fertility that promote rapid bean growth can minimise the potential of *A. fabae* damage. The value of such an approach is fully recognised (Painter, 1951, 1958).

Where potentially heavy *A. fabae* infestation threaten to cause economic crop loses, chemical control inspite of its undesirable side effects on pest natural enemies, pollinators and on the environment in general is still the most effective solution. Observations in the current studies revealed that serious damage to beans was mainly associated with *A. fabae* infestation that occurred during the first five weeks of bean growth and development. In early planted field beans, a single judicious application of an effective aphicide during the early stage of bean growth was found adequate in controlling *A. fabae* without causing harm to bees and other insect pollinators (Way, 1961). This strategy could also be adopted by Kenyan farmers in their attempts to reduce bean yield losses due to aphids.

However, in other studies chemical control was found to be ineffective against very heavy *A. fabae* infestation that occurred on late planted beans (Ingram, 1969). This worker noted that under such heavy aphid build-up chemical control failed because of continuous re-infestation and the uneconomic consequence of repeated spraying. It is also possible that an ineffective spraying process could lead to stimulated aphid dispersal within the crops. Such *A. fabae* dispersal could lead to a greater spread of bean virus diseases, thus aggravating aphid problems (Cockbain *et. al.*, 1963).

Because of the dynamic nature of *A. fabae* infestation, bean resistance to the aphids and to some of the important virus diseases they transmit constitutes the most valid long-term option for minimising aphid and virus damage and stabalising yields. The various advantages of crop plants resistant to insect pests are well known (Painter, 1951, 1958; Pathak, 1970; Horber, 1972; Beck, 1965). Observations from the current studies revealed that some of the varieties of beans currently grown in Kenya possess varying degrees of resistance to *A. fabae*. A potential therefore exists already for the development of bean varieties that possess enhanced resistance to this pest.

In conclusion, investigations in the present studies have demonstrated the serious potential of A. fabae as a pest of common beans in Kenya. It was also shown that serious damage to beans from A. fabae attack or through the transmission of CBMV was limited to aphid infestation that occurred before flowering. It was thus felt that control of the pest during these stages of bean development was probably worthwhile. These studies also showed that early planting and good agronomic practices minimised the potential of aphid damage on beans. Furthermore, the different varieties of beans tested showed varying degrees of resistance to A. fabae, strongly indicating that the potential exists for developing varieties with relatively good resistance to the pest.

Finally, it has been shown in these studies that in order to overcome the problem of A. fabae damage on common beans, advantages of improved agronomic practices, judicious use of aphicides, crop resistance and aphid natural enemies must be jointly considered in bean production. To achieve the above mentioned goal further studies on the exact mechanism of the resistance of beans to aphids must be undertaken so as to develop bean varieties that are adequately resistant to the pest.

Investigations of the roles of the various natural enemies of *A. fabae* on the population dynamics of the pest would also be useful in evolving an integrated approach to the management of this pest.

Appendix I: The means of the various parameters of common beans infested at two levels of *A. fabae* populations during four stages of plant development.

Plant parameters	No. of aphids/ plant	Stage of bean development			
		early vegetative	late vegetative	anthesis	grain filling
height of central shoots (cm)	6 (high)	35.00[a]	53.50[b]	57.33[bc]	59.83[c]
	3 (low)	43.00[a]	57.33[b]	58.50[b]	59.67[b]
length of axillary shoots (cm)	6 (high)	13.33[a]	102.50[b]	136.83[c]	141.33[c]
	3 (low)	43.67[a]	112.50[b]	137.17[c]	146.83[c]
number of flowers per plant	6 (high)	14.17[a]	41.17[b]	67.39[c]	71.23[c]
	3 (low)	15.67[a]	44.00[b]	68.00[c]	70.87[c]
Number of pods per plant	6 (high)	2.01[a]	4.67[b]	6.67[c]	9.83[d]
	3 (low)	4.83[a]	6.33[b]	7.50[c]	9.33[d]
number of seeds per pod	6 (high)	2.53[a]	3.32[b]	3.69[bc]	3.83[c]
	3 (low)	2.84[a]	3.42[b]	3.70[bc]	3.84[c]
number of seeds per plant	6 (high)	5.00[a]	15.50[b]	23.83[c]	37.83[d]
	3 (low)	13.83[a]	20.67[b]	27.83[c]	36.00[d]
weight of seeds per plant (gm)	6 (high)	3.68[a]	10.53[b]	12.41[c]	23.12[d]
	3 (low)	8.47[a]	13.17[b]	17.10[c]	22.85[d]

a,b,c,d: for each level of *A. fabae* populations means denoted by the same letter are not significantly ($P = 0.05$) different (Duncan's (1955) New Multiple Range Test).

Appendix II: A summary of the analyses of variance for the various parameters of common beans infested at two levels of <u>A</u>. <u>fabae</u> populations during four stages of plant development.

Source of variation	df	mean squares: height (cm) of central shoots	length (cm) of axiallary shoots	number of flowers/ plant	number of pods/ plant	number of seeds/ pod	number of seeds/ plant	weight (gm) seeds/ plant
total	47							
level of infestation(L)	1	123.521*	1463.02**	15.19	17.52	0.435	196.62*	44.87
Stage of development(S)	(3)							
linear	1	2438.438**	85390.54**	21600.22**	241.51*	7.255**	4896.58**	1388.73**
quadratic	1	638.021**	15087.52**	2762.58**	0.14	0.473	3.42	2.92
cubic	1	158.437**	348.00	23.43	2.08	0.002	35.80	44.21
interaction L x S	3	46.243	526.80	6.35	5.91	0.125	58.54	14.56
error	40	20.646	137.44	21.51	1 41	0.185	30.35	7.60
CV (%)		8.55	11.27	9.46	18.57	12.59	24.42	19.81
SE of a level mean		0.927 cm	2.393 cm	0.947	0.242	0.088	1.125	0.563
SE of a stage mean		1.312 cm	3.384 cm	1.339	0.343	0.124	1.590	0.796

Significant: *P = 0.05 ** P = 0.05

Appendix III: The means of various parameters of common beans infested with virus-free and virus-carrying A. fabae at two levels of populations during four stages of development.

Plant parameters	virus status	no aphid/ plant	stages of bean development: early vegetative	late vegetative	anthesis	grain filling
Height of central shoots (cm)	VF	6 (high)	35.07^{a}	53.35^{b}	57.52^{b}	59.86^{b}
		3 (low)	41.13^{a}	58.81^{b}	57.65^{b}	59.94^{b}
	VC	6 (high)	24.24^{a}	44.56^{b}	56.99^{c}	59.73^{c}
		3 (low)	29.35^{a}	50.72^{b}	57.91^{b}	59.80^{b}
length (cm) of axillary shoots	VF	6 (high)	13.33^{a}	102.50^{b}	136.83^{c}	144.33^{d}
		3 (low)	43.67^{a}	110.51^{b}	137.17^{c}	144.83^{d}
	VC	6 (high)	8.50^{a}	72.33^{b}	118.33^{c}	143.65^{d}
		3 (low)	26.67^{a}	77.33^{b}	119.17^{c}	146.33^{d}
number of flower/ plant	VF	6 (high)	13.00^{a}	41.33^{b}	67.67^{c}	71.01^{d}
		3 (low)	14.67^{a}	44.17^{b}	69.50^{c}	71.19^{c}
	VC	6 high)	3.67^{a}	12.05^{b}	69.31^{c}	71.67^{c}
		3 (low)	3.83^{a}	16.13^{b}	68.67^{c}	70.67^{c}
number of pods/plant	VF	6 (high)	2.08^{a}	4.67^{b}	6.67^{c}	9.83^{d}
		3 (low)	4.83^{a}	6.33^{b}	7.50^{c}	9.63^{d}
	VC	6 (high)	0.83^{a}	2.89^{b}	7.72^{c}	9.53^{d}
		3 (low)	1.33^{a}	3.36^{b}	6.68^{c}	9.36^{d}
number of seeds/ plant	VF	6 (high)	5.01^{a}	15.50^{b}	23.83^{c}	36.13^{d}
		3 (low)	13.83^{a}	20.67^{b}	27.53^{c}	37.83^{d}
	VC	6 (high)	1.17^{a}	9.01^{b}	22.88^{c}	36.07^{d}
		3 (low)	3.10^{a}	10.17^{b}	27.80^{c}	37.53^{d}
Weight (gm) of seeds/plant	VF	6 (high)	3.67^{a}	10.53^{b}	12.41^{c}	23.12^{d}
		3 (low)	8.47^{a}	13.17^{b}	17.10^{c}	22.84^{d}
	VC	6 (high)	0.38^{a}	3.93^{b}	11.94^{c}	22.82^{d}
		3 (low)	1.43^{a}	5.62^{b}	16.98^{c}	23.09^{d}

VF = virus-free aphids; VC = virus-carrying aphids.

a,b,c,d: for each level of A. fabae populations means denoted by the same letter are not significantly (P = 0.05) different (Duncan's (1955) New Multiple Range Test).

Appendix IV: A summary of the analyses of variance of the various parameters of common beans infested with virus-free and virus-carrying *A. fabae* at two levels of populations during four stages of development.

		mean squares					
		height (cm) central shoots	length (cm) axillary shoots	number of flowers/ plant	number of pods/ plant	number of seeds/ plant	weight (gm) seeds/ plant
source of variation	df						
total	95						
stage of development (D)	3						
linear	1	8738.13**	193523.01**	61676.00**	737.55**	13356.30**	5059.48**
quadratic	1	1650.04*	15606.00**	1708.59**	1.26	54.00	69.84**
cubic	1	106.42	116.03	4052.28**	1.30	28.03	0.04
virus status (S)	1	651.05	5400.00**	2271.76**	33.84**	379.04**	225.40**
level of infestation (L)	1	216.01	1890.38**	25.01	19.26**	234.38**	143.72**
interaction D x S	3	213.00	1111.42**	1120.06**	11.29**	124.71*	78.51**
interaction D x L	3	84.47	665.90**	16.98	2.87	30.82	22.76
interaction S x L	1	1.03	112.66	2.34	2.34	20.17	6.36
interaction D x S x L	3	6.18	44.64	419.04**	3.12	32.50	5.50
error	80	296.66	122.02	15.60	1.40	28.90	7.68
CV (%)		32.57	11.44	8.92	20.46	26.20	22.45
SE of a stage mean		3.352 cm	2.255 cm	0.806	0.242	1.097	0.566 gm
SE of a status or level mean		2.370 cm	0.627 cm	0.570	0.171	0.776	0.400 gm

Significant *P = 0.05; **P = 0.01

Appendix V: The means of the various parameters of common beans grown using two levels of soil moisture and fertility, and infested with *A. fabae* at four stages of development.

Plant parameters	fertilizer level	moisture level	stages of bean development: early vegetative	late vegetative	anthesis	grain filling
height (cm) of central shoots	0.0g	0.5ℓ	41.50^{a}	86.01^{b}	126.00^{c}	148.83^{d}
		2.0ℓ	94.33^{a}	135.17^{b}	141.17^{b}	174.17^{c}
	10.0g	0.5ℓ	73.67^{a}	99.17^{b}	140.67^{c}	151.17^{c}
		2.0ℓ	118.33^{a}	164.83^{b}	184.33^{c}	306.33^{d}
number of flowers/plant	0.0g	0.5ℓ	5.50^{a}	40.83^{b}	81.33^{c}	81.67^{c}
		2.0ℓ	13.33^{a}	55.67^{b}	100.33^{c}	101.67^{c}
	10.0g	0.5ℓ	6.17^{a}	52.38^{b}	86.83^{c}	88.67^{c}
		2.0ℓ	20.33^{a}	58.34^{b}	101.35^{c}	102.28^{c}
number of pods/plant	0.0g	0.5ℓ	2.33^{a}	3.33^{b}	4.35^{b}	4.88^{b}
		2.0ℓ	7.00^{a}	7.33^{a}	8.38^{b}	11.79^{c}
	2.0g	0.5ℓ	4.68^{a}	5.67^{ab}	5.88^{b}	8.17^{c}
		2.0ℓ	9.12^{a}	9.83^{a}	11.17^{b}	16.21^{c}
number of seeds/plant	0.0g	0.5ℓ	9.83^{a}	16.17^{b}	20.01^{bc}	23.33^{c}
		2.0ℓ	39.17^{a}	39.50^{a}	41.00^{a}	66.50^{b}
	2.0g	0.5ℓ	20.51^{a}	23.35^{ab}	28.31^{b}	40.89^{c}
		2.0ℓ	48.12^{a}	56.50^{b}	58.67^{bc}	99.83^{c}
weight (gm) of seeds/plant	0.0g	0.5ℓ	1.92^{a}	3.94^{ab}	5.20^{bc}	6.44^{c}
		2.0ℓ	8.97^{a}	11.29^{b}	14.87^{c}	18.93^{d}
	2.0g	0.5ℓ	4.90^{a}	6.07^{a}	8.13^{b}	11.13^{c}
		2.0ℓ	14.26^{a}	15.62^{a}	18.79^{b}	29.62^{c}

a,b,c,d: for each level of soil moisture means denoted by the same letter are not significantly (P = 0.05) different (Duncan's (1955) New Multiple Range Test).

Appendix VI: A summary of the analyses of variance of the various parameters of common beans grown using two levels of soil moisture and fertility, and infested with *A. fabae* at four stages of development

		mean squares				
		height (cm) central shoots	number of flowers/ plant	number of pods/ plant	number of seeds/ plant	weight (gm) seeds/ plant
source of variation	df					
total	95					
stage of bean development (D)	3					
linear	1	160089.07**	99216.25**	261.07**	9091.50**	1047.49**
quadratic	1	360.38NS	9106.51**	18.36*	1344.01**	56.98*
cubic	1	1548.05NS	1932.02**	7.01NS	427.52*	2.55NS
level of soil fertility (F)	1	30960.21**	446.34**	150.00**	5355.10**	511.16**
level of soil mositure (M)	1	75152.08**	4496.34**	651.04**	26967.51**	2682.03**
interaction D x F	3	2694.77**	14.68	4.89	279.76	26.13
interaction D x M	3	3973.28**	84.62*	15.15**	870.76**	69.22**
interaction F x M	1	10416.62**	71.76	4.17	148.78	50.08**
interaction F x M x D	3	5511.62**	72.58*	0.28	96.57	7.00
Error	80	490.42	22.08	2.79	100.90	10.42
CV %		16.21	7.55	22.29	25.44	28.68
SE of a stage mean		4.521 cm	0.959	0.341	2.050	0.659
SE of a fertility and moisture mean		3.197 cm	0.678	0.241	1.450	0.466

Significant: *P = 0.05; **P = 0.01

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