THE BIOLOGY AND BEHAVIOUR OF *NEOSEIULUS IDAEUS* (DENMARK AND MUMA) (ACARINA: PHYTOSEIIDAE) REARED ON NATURAL AND ARTIFICIAL MEDIA

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D E C L A R A T I O N

I Edna Chisaokwu Nwofor, hereby declare that, the work presented in this thesis is my original work and has not been submitted for a degree in any other University.

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D E D I C A T I O N

Dedicated To

Baba and Nanna

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A B S T R A C T

The biology and behaviour of Neoseiulus idaeus (Denmark and Muma) was compared on natural and artificial diets under controlled laboratory conditions (27°C and 80% R.H.). The predator culture was maintained on a diet of red spider mites (Tetranychus spp.) while the prey was maintained on bean leaves (Phaseolus vulgaris L.).

Five developmental stages namely, egg, larva, protonymph, deutonymph, and adult, common to phytoseiids were observed on the natural diet. The mites did not develop beyond the protonymph stage when maintained on the artificial diets.

Eggs are laid singly on leaf hairs or in the web strands of the prey. The males are bronze coloured and smaller than the females and some female deutonymphs. The females are light orange coloured and bigger than the other stages.

Observed fecundity was low owing to high mortality in the ovipositing females. Mating was necessary for oviposition. Unmated females did not oviposit. Repeated mating was required for continued oviposition and for the females to lay their full complement of eggs.

Longevity was compared on natural diet, artificial liquid diet, artificial solid diet, a no-food situation and a modified artificial liquid diet. The mites lived significantly longer on the natural diet than on the other food situations. There was no significant difference in the longevity of the mites on the rest of the diets.

N. idaeus preferred the eggs of its prey to the other stages. The larva did not feed. Cannibalism was observed in the absence of its prey.

The highest mortality was recorded at the adult stage. The intrinsic rate of increase was quite high (0.845 per head per day) with a short generation time (2.969 days).

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Cassava, Manihot esculenta Crantz (Euphorbiaceae) is a major energy source for over 300-500 million people in Africa (Byrne et al., 1983; Bellotti, 1985) with an annual global production of 120 million tons on 13.7 million hectares of land (Bellotti, 1985). It is widely cultivated throughout the tropical regions of the world. This crop, which is native to Latin America, was introduced into the delta of the Congo River by the Portuguese during the latter part of the sixteenth century, and in East Africa in the early nineteenth century (IITA Inform. Series, No. 16, 1986). The historical increase in its popularity has been ascribed to its resistance to pest attack particularly to arthropod pests; its adaptation to harsh environmental conditions such as exhausted soils; its effectiveness as a famine relief crop of semi-arid drought areas (Kirkby, 1984); its tolerance to severe drought conditions; and simplicity in its cultivation which does not require much effort and inputs. However, the crop has received very little attention from scientists and policy makers.

Cassava is grown on an estimated 80 million hectares in thirty four African countries (Theberge, 1985). Kenya cultivated 95,000 ha. in 1983 (Githunguri, Ndonga and Amadalo, 1984). In Malawi, 82,000 ha. are cultivated (Sauti, 1984) and in Zanzibar, more than 20,000 ha. are cultivated per year (Makame and Said, 1984). In Nigeria, over 200,000 ha. have already been planted to IITA developed high-yielding, disease resistant cultivars (IITA Inform. Series No. 16, 1986). In Burundi, cassava production is estimated at 444,000 tonnes, with an average yield of 6 tonnes per hectare (Ndayiragije, 1984). In 1983, Uganda produced 3,255 tonnes of fresh cassava (Odongo, 1987).

In many African countries cassava is grown mainly for human consumption and occasionally for livestock feed. In Malawi, cassava forms a staple food for about 15% of the population (Sauti, 1984). In Burundi, Uganda, Zanzibar and Kenya, Sweet and bitter varieties are grown and eaten as staple food by the people. In Tanzania 84% of the total cassava produced is used for home consumption (Msabaha, 1984).

Locally, the cassava leaves are eaten as vegetable after boiling to remove the cyanic acid contained in the leaves. As food for livestock cassava is given in form of pellets or mixed with some commercial feeds. In Brazil cassava is used to manufacture adhesives, paper, starch,

bread, ferments, alcohol and acetone. In the Dominican Republic, cassava is exported to the United States for the manufacture of starch.

Cassava is attacked from time to time by many arthropod pests. These include locusts, grasshoppers, termites, white flies and cassava scales.

In recent years cassava has been attacked by two very devastating pests: the cassava mealybug (CMB) (Phenacoccus manihoti Matile Ferrero) (Hemiptera: Pesudococcidae), and the cassava green spider mite (CGSM) (Mononychellus tanajoa)(Bondar)) (Acari: Tetranychidae).

The cassava green spider mite was first reported in Uganda in 1971 (Nyiira, 1972, Lyon, 1974). Ndayiragije (1984) reported it in Burundi in 1973 on cassava varieties in the Imbo Region (altitude 840m). It is suspected to have been accidentally introduced into Uganda from Latin America (Girling, 1977) from where it spread to other neighbouring countries, virtually covering all the cassava growing regions of Africa (Yaseen and Bennett, 1977; Ingram, 1984; Yaninek and Animashaun, 1986).

Severe attack of cassava green spider mite on cassava is mainly directed at the top young leaves (Nyiira, 1972; van den Berg, 1985). Symptoms of damage include yellow spots on leaves which under heavy

infestation coalesce giving a mottled mosaic-like appearance (Yaninek, 1986). There is an estimated 95% reduction in the surface area of the leaf (IITA Inform. Series, No. 16, 1986). This factor together with the chlorosis of the leaves reduces the photosynthetic activity and a consequent reduction in the root yield of the crop.

The reduction in root weight due to mite attack varies according to a number of factors such as type of ecology, cassava variety (susceptible or resistant), season of the year (dry/wet season), stage of plant attacked, and the population level of the mites (Nyiira, 1978; Byrne et al., 1982).

Various workers have attempted to quantify the reduction in weight due to mite attack. The estimates in different countries are as follows: Uganda, about 46% (Nyiira, 1975); Tanzania, 50-80% (Shukla, 1978); Venezuela, 15-20%, and Colombia, 20-53% (Bellotti and Schoonhoven, 1978); and Burundi, 13-32% (Ndayiragije, 1984).

The value of annual global losses due to mite attack was estimated to be 860 million U.S. dollars. This value excludes the loss of leaf vegetable and planting materials. The loss in total root yield in thirty African countries is estimated at 80% and the value of

lost produce estimated to be 2.0 billion a year (IITA Inform. Series, No. 16, 1986). Yaninek and Herren (1987) estimated the yield losses to range from 13-80% indicating how threatening the cassava green spider mite is to cassava producers in many areas.

The spread of this mite in Africa is estimated to be about 375 km $year^{-1}$ (IITA Inform. Series, No. 16, 1986). Because of this concern the Commonwealth Institute of Biological Control (CIBC) West Indian Station in Trinidad conducted surveys between 1974 and 1979 of cassava mites and their natural enemies in Mexico, Central America, Colombia, Peru, Guyana, Surinam, Guyane (French Guina) Northeastern Brazil and in some Caribbean Islands (Murphy, 1984).

In order to establish the identity of this green spider mite and some of its effective predators, additional surveys were conducted between 1979 and 1981 in Venezuela, Ecuador, Bolivia, Paraguay and in Southern and North western Brazil. The most common predators in the neotropics were found to be several phytoseiid mites and coccinellid beetles. These were Amblyseius largoensis (Muma) and Euseius concordis (Chant) (found) in Tobago); Amblyseius brazilli El-Banhawy (found in Ecuador); Amblyseius hibisci (Chant) (found in Bahamas); Euseius fructicolus (Gonzales and Schuster) and

Neoseiulus idaeus (Denmark and Muma) (both found in Paraguay); Phytoseiulus macropilis Banks (found in Peru); Typhlodromalus limonicus (Garman and McGregor)(found in Bolivia, Brazil, Colombia, Ecuador, Trinidad and Venezuela etc.); and Oligota minuta Cam (found in Brazil, Cuba, Bahamas and Colombia). Other predators in the family Anthocoridae (Hemiptera) and Cecidomyiidae (Diptera) were also found in French Guyana and Colombia respectively (Murphy 1984). Although the distribution of the predators was comprehensively documented, unfortunately there has been no detailed information about their host specificity and seasonal occurrence.

The complex of indigenous natural enemies found associated with cassava green spider mite in Africa is similar in composition but not in effectiveness to that present in the neotropics (Nyiira and Mutinga, 1977; Yaninek and Herren, 1987). Perhaps this is due to the cassava green spider mite being an exotic species with specialized predators. Hence the search for its natural enemies in the neotropics.

Three attempts were made to introduce natural enemies for control of the cassava green spider mite. The first attempt was made in Kenya in 1977, followed by others in Zaire in 1978 and in Kenya in 1983 (Murphy, 1984). The releases were presumed to have failed to establish because no recoveries were made from the original release sites.

In 1983, few new phytoseiids were shipped to the International Institute of Tropical Agriculture (IITA) in Nigeria. N. idaeus was one of such natural enemies. This phytoseiid was first described in Brazil by Denmark and Muma (1973). It was found on Rubus idaeus from Piracicaba in the city of Sao Paulo, Brazil by C.H.W. Fletchman in 1967 (Denmark and Muma, 1973). De Moraes and McMurtry (1983) reported its occurrence in the humid as well as the drier areas of Northeastern Brazil. The authors found it associated, among others, the green spider mite, M. tanajoa. Van den Berg (1985) described its biology briefly. Dinh et al. (1986, 1987) reported on the influence of humidity and water availability on its survival and its reproductive success on a diet of two-spotted spider mites.

The aim of the present study is to examine and compare the biology and behaviour of this mite on the natural as well as on artificial media.

1. LITERATURE REVIEW

1.1 Phytoseiid Biology on Natural Diet

1.1.1 Life Cycle and Development

Phytoseiids have four developmental stages namely: the oval-shaped egg, the six-legged larva, the eight-legged protonymph and deutonymph (Sabelis, 1985). The deutonymph stage precedes the adult stage. This observation has been reported for a number of phytoseiids such as Amblyseius cucumeris (Oudemans), Typhlodromus caudiglans Schuster, Phytoseiulus persimilis Athias-Henriot Amblyseius brazilli El-Banhawy, and Amblyseius fustis (Pritchard and Baker) (El-Badry and Zaher, 1961; Putman, 1962; Laing, 1968, Amano and Chant, 1977, Thurling, 1980; El-Banhawy, 1975; Ezulike and Odebiyi, 1985). Amblyseius umbraticus Chant, Phytoseius fotheringhamiae Denmark and Schicha and Amblyseius citrifolius (Denmark and Muma) have also been reported to pass through similar stages of development (Knisley and Swift, 1971; Schicha, 1975; De Moraes and McMurtry, 1981). However, Ballard (1954) reported that the males of Amblyseius fallacis (Garman) (= Typhlodromus fallacis) do not pass through the deutonymph stage before becoming adults except the females.

The eggs of phytoseiids are generally laid on top of leaf hairs, grooves close to the most prominent leaf ribs or stuck to the web strands produced by their

tetranychid prey (Sabelis, 1985). Collyer (1956) reported that the eggs of P. macropilis, Typhlodromus tiliae (Oudemans) (= Typhlodromus pyri Scheuten), and Typhlodromus soleiger (Ribaga) are laid singly on the ventral surface of the leaves where they may be placed on the leaf itself, at the tip of a leaf hair, or suspended in the web strands of a tetranychid prey. Ballard (1954) observed that the eggs of A. fallacis are laid singly yet the females tend to place them in groups within the cell. However, Tanigoshi and McMurtry (1977) reported that the eggs of Typhlodromus floridanus (Muma) are laid in clusters.

A sticky substance on the egg chorion which attaches the egg firmly to the substratum was reported for A. fallacis, Typhlodromus occidentalis Nesbitt, A. umbraticus, A. citrifolius and A. fustis (Ballard, 1954; Lee and Davis, 1968; Knisley and Swift, 1971; De Moraes and McMurtry, 1981; Ezulike and Odebiyi, 1985). The fresh egg is translucent and without colour but it soon changes to the colour of food offered to the ovipositing female (Prasad, 1967). Laing (1969) reported that the eggs of Metaseiulus occidentalis Nesbitt are translucent when freshly laid, but as incubation progresses they become opaque, white and shiny. Tanigoshi and McMurtry (1977) observed that the eggs of T. floridanus are glossy and transparent when freshly laid, but later turn whitish, opaque and granular.

Incubation period varies according to the species studied and the experimental conditions. It also varies according to the sex of the phytoseiid studied. Varied incubation periods have been reported for various other phytoseiids such as P. persimilis, Amblyseius andersoni Chant and Phytoseius hawaiiensis Prasad (Amano and Chant, 1977; Sanderson and McMurtry, 1984).

The process of eclosion differs from species to species depending on experimental conditions (see Prasad, 1967, Lee and Davis, 1968; and De Moraes and McMurtry, 1981, for details). After eclosion the larva emerges with three pairs of legs. In some species, such as Amblyseius finlandicus (Oudms), A. hibisci, A. limonicus and T. occidentalis, the larvae have been observed to feed (Chant, 1959; McMurtry and Scriven, 1964; Burrell and McCormick, 1964, Lee and Davis 1968). In other species including, Typhlodromus rickeri (Chant), P. macropilis, P. persimilis, and Typhlodromus persianus n.sp from Iran feeding has not been observed (McMurtry and Scriven, 1964; Prasad, 1967; Laing, 1968; Amano and Chant, 1977; McMurtry, 1977). The adult stage is reached via moulting. In species such as A. fallacis, T. rickeri, and A. citrifolius, the larva may pass through a period of quiescence prior to moulting (Ballard, 1954; McMurtry and Scriven, 1964; De Moraes and McMurtry, 1981). In others such as P. persimilis there is no distinct quiescent stage (Laing, 1968). Sabelis (1985) reported that the moulting process does

not seem to take place at specific sites or at specific times. But Blommers (1974) observed that the nymphs of Amblyseius vazimba Blomers and Chazeau moult during the night or early in the morning independent of the time of the day the original egg was laid.

The protonymph feeds immediately on emergence and becomes bigger. The nymphal stages as well as the adults vary in their colour gradients depending on the type of prey they consume (El-Baldry and Zaher, 1961; Prasad, 1967; Laing, 1968).

1.1.2 Measurements

The sizes of phytoseiids vary according to the species, and within the species, according to the stages of development. Womersely (1954) stated that the size of phytoseiids ranges from 300-600 microns in length. Chant (1985) reported that adult phytoseiids are rarely longer than 500 µm, and Sabelis (1985) observed that phytoseiids are generally less than 1 mm in length. Womersely (1954) studied and measured the species found in Australia. He measured the lengths and the widths of the idiosoma and found that these vary according to the species. He observed that for A. fallacis the length of the idiosoma was 345 µ while the width was 200 µ. On the other phytoseiids, he reported 357 x 201 µ for Typhlodromus longispinosus Owen Evans, 364 x 234 µ for Typhlodromus bellinus sp. nov, 414 x 273 µ for Typhlodromus nesbitti

sp. nov. and 390 x 270 µ for Typhlodromus victoriensis sp. nov. He also reported 390 x 260 µ for Kampidromus australicus sp. nov. and 390 x 260 µ for Amblyseius obtusus Berl (=Zercon obtusus Koch).

Different authors have also reported varying sizes for other phytoseiids such as T. tiliae, T. finlandicus, Amblyseius spiculatus Denmark and Muma, N. idaeus, N. transvaalensis, T. persianus, Amblyseius solus - and Euseius saltus Denmark and Muma, and E. hibisci (Collyer, 1956; Denmark and Muma, 1973; McMurtry, 1977; Matthysse and Denmark, 1981; De Moraes and McMurtry, 1983; Congdon and McMurtry, 1985). In some cases, only the setal measurements are given (McMurtry, 1980; Congdon and McMurtry, 1986).

The various life stages have also been reported to differ in size according to the species studied, namely, A. fallacis, T. occidentalis, A. umbraticus, P. macropilis, and A. fustis (Ballard, 1954; Lee and Davis, 1968; Knisley and Swift, 1971; Prasad, 1973; Ezulike and Odebiyi, 1985).

Chant (1985) reported that for Typhlodromus species the length of the dorsal shield varies from less than 300 µm to almost 500 µm such as in T. pyri. But in Phytoseius spp. he reported that the shield size varies between 250 - 300 µm.

1.1.3 Fecundity and Sex Ratio

Females in the oviposition phase have much higher food demands than in any other phase or stage. This is because egg production requires much food as a lot of food is invested in the egg (Sabelis, 1985). They also invest relatively more biomass in producing large eggs. Sabelis stated that the total egg biomass that can be produced by a phytoseiid female per day is equivalent to the biomass of the female herself. He reported that at 30°C a young female of *P. persimilis* produces 5 eggs of 4.5 µg each per day which represents a mass equivalent to her live weight. Hence ovipositing females have high food requirements. Therefore the most obvious constraint on reproduction is the availability of food. So, fecundity, rate of oviposition and length of oviposition are dependent on the quantity of food available. They are also dependent on the type of prey, the mating behaviour of the adult mites, the duration of oviposition and the longevity of the ovipositing female. These are also influenced by temperature and relative humidity.

Many phytoseiids such as *A. fallacis*, *Typhlodromus athiasae* Porath and Swirski, and *P. persimilis* differ in their fecundity and length of oviposition period depending on the type of prey offered to the ovipositing female (Ballard, 1954; Swirski *et al.*, 1967; Laing, 1968). Other phytoseiids reported to show similar behaviour are

A. brazilli, Amblyseius californicus McGregor, M. occidentalis, and P. hawaiiensis (El-Banhawy, 1975; Friese and Gilstrap, 1982; Sanderson and McMurtry, 1984). Croft and Jorgensen (1969) reported that the number of prey consumed per female of Typhlodromus mcgregori Chant influenced its rate of egg production.

Fecundity, oviposition rate, and length of the oviposition period also vary depending on the species of predator, even when fed the same food source and reared under the same laboratory conditions. Amano and Chant (1986) reported a similar observation for Typhlodromus pomi Parrott, P. macropilis and A. finlandicus.

Temperature has been reported to influence fecundity and rate - and length of oviposition in phytoseiids such as Amblyseius bibens Blommers, A. citrifolius and Amblyseius tetranychivorus (Gupta) (Blommers, 1976; De Moraes and McMurtry, 1981; Krishnamoorthy, 1982). Sabellis (1985) stated that at 25°C the average oviposition period for phytoseiids is 15-30 days. He stated that this period is usually shorter the higher the rate of reproduction. This is similar to the observation of Takafuji and Chant (1976) and Amano and Chant (1977, 1986) in respect of P. persimilis and A. filandicus. In some species constant mating led to maximum fecundity and increased the oviposition period (Putman, 1962; McMurtry

and Scriven, 1964; El-Baldry and El-Banhawy, 1968; Laing, 1968; Knisley and Swift, 1971; Takafuji and Chant, 1976). However, in some others constant mating did not influence fecundity or period of oviposition (Lee and Davis, 1968; Laing, 1969; Smith and Newsom, 1970; Takafuji and Chant, 1976; McMurtry, 1977; Amano and Chant, 1978). El-Baldry and El-Banhawy (1968) indicated that multiple mating in Amblyseius gossypii El-Badry caused a shift in the sex ratio from 1.5 females to 1 male (1.5:1) in single mated females and 2 females to 1 male (2:1) in females that had repeated mating.

The duration of copulation has been reported to influence fecundity and oviposition period in P. persimilis, A. andersoni, and A. bibens (Amano and Chant, 1978; Schulten, 1985). Schulten (1985) further reported that a longer copulation period results in a shift in the sex ratio largely in favour of females.

1.1.4 Mating Behaviour and Parthenogenesis

Amano and Chant (1978) reported that mating in phytoseiids takes place in a venter-to-venter position with the male underneath the female. Mating takes place immediately after the final moult; and unmated females do not oviposit (Amano and Chant, 1978, 1986; Schulten et al., (1978)

Amano and Chant (1978) described two types of mating behaviour common in phytoseiids: the "Amblyseius -

Typhlodromus" type and the "Phytoseiulus" type. In the former, the authors reported that the males first climb upon the dorsum of the female and later crawl underneath her and both mate venter-to-venter. In the "Phytoseiulus" type the authors stated that all the pairs make contact in a face to face position with their palps and first pair of legs touching each other. The males then invert themselves in three different variations and crawl underneath the female in a venter-to-venter position. Prasad (1967) reported this type of mating behaviour in P. macropilis. The phytoseiids that show the Amblyseius - Typhlodromus type of mating behaviour include A. fallacis (Ballard, 1954), T. tiliae (Herbert 1956), Amblyseius cucumeris (Oudemans) (El-Badry and Zaher, 1961), A. gossypii (El-Badry and El-Banhawy, 1968), T. occidentalis (Lee and Davis, 1968), A. andersoni (Amano and Chant, 1978), A. finlandicus, P. macropilis and T. pomi (Amano and Chant, 1986). In these species the duration of copulation period varied according to the species. Ballard (1954) reported a copulation period of 2-3 hours for A. fallacis while El-Badry and Zaher (1961) reported 2-5 hours for A. cucumeris. Prasad (1967) reported a mating period of 89.9 minutes for P. macropilis while Amano and Chant (1978) reported 185.00±19.01 minutes for A. andersoni and 131.07±20.83 minutes for P. persimilis. Herbert (1956) showed that the duration of copulation depends on

temperature. He observed that copulation in T. tiliae lasted for 4-6 hours at 70°F and 14-38 hours at 60°F.

In phytoseiids mating is necessary for oviposition (Amano and Chant, 1978; Schulten et al., 1978). Wysoki (1985) stated that thelytokous parthenogenesis had been discovered in seven species of phytoseiids among which were: Amblyseius elongatus (Garman) (= Amblyseius guatemalensis (Chant) (Kennett, 1958), Typhlodromus transvaalensis (Nesbitt) (Amitai et al., 1969), and Amblyseius parasundi Blommers (Blommers, 1974). He stated that among the seven species three instances of male occurrence had been reported. Parthenogenesis has also been observed in A. teke (E. Amboga, Pers. Comm.).

Matthysse and Denmark (1981) also reported thelytoky in some phytoseiids such as Amblyseius sundi Pritchard and Baker, Paraseiulus parva Denmark and Matthysse and Amblyseius solus Denmark and Matthysse (see Matthysse and Denmark, 1981).

1.1.5 Longevity

Sabelis (1985) stated that the life span of adult phytoseiids could be divided into preoviposition period of only a few days, oviposition period of 15-30 days at 25°C and a post oviposition period of variable length at the same temperature.

Adult phytoseiids differ in the length of their life span, even when reared under the same laboratory conditions. Ballard (1954) reported that adult females and males of A. fallacis lived an average of 32.2 days at 80°F and 95% R.H., with Tetranychus bimaculatus Harvey as the main prey. Collyer (1956) reported an adult life span of 52 days for T. tiliae, 71 days for T. umbraticus, and 77 days for P. macropilis, under the same laboratory conditions. P. persimilis and I. degenerans Berlese also differed in their life span under the same laboratory conditions (Takafuji and Chant, 1976).

In some phytoseiids such as A. cucumeris and T. occidentalis, the females live longer than the males (El-Baldry and Zaher, 1961; Lee and Davis, 1968). El-Banhawy (1975) reported an average life span of 30 days for the females of A. brazilli under a temperature of 9-24°C and a relative humidity of 80%. Blommers (1976) reported that the life span of female A. bibens is extremely long; and Sanderson and McMurtry (1984) reported a life span of 113.6±50.66 days for the adult female of P. hawaiiensis at 24°C and 60% R.H.

Mating behaviour has been shown to influence longevity. Many authors reported that unmated females and those exposed to males for a short period live longer than the mated females and those exposed to males throughout their life. Similar observation was reported by

Knisley and Swift (1971) for A. umbraticus, and Amano and Chant (1977) for P. persimilis. Sabelis (1985) also reported that unmated females live much longer than the mated ones.

Longevity of a mite can be influenced by the type of prey it consumes such as was observed in Typhlodromus longipilus Nesbitt, Typhlodromus rhenanus (Oudms.) and A. fallacis (Burrell and McCormick, 1964). Longevity is also influenced by temperature (Smith and Newsom, 1970; De Moraes and McMurtry, 1981; Badii and McMurtry, 1984). Longevity decreases in absence of food as was reported for P. persimilis, I. degenerans and A. bibens (Takafuji and Chant 1976; Blommers and Van Arendonk, 1979). Mori and Chant (1966) reported that free water and high humidity promoted the life span of P. persimilis while absence of water and low humidity shortened the life span.

1.1.6 Feeding

Phytoseiid mites feed on diverse forms of natural food sources ranging from plant juices (Chant, 1959; Chant and Fleschner, 1960; Porres et al., 1975) to different species of tetranychid mites (Fleschner and Ricker, 1954; Herbert, 1959; Schuster and Pritchard, 1963; Ragusa and Swirski, 1977; De Moraes and McMurtry, 1981; McMurtry et al., 1984), and pollen from different plants including honeydew, mildew and insect crawlers (Herbert,

1959; Putman, 1962; Putman and Herne, 1964; McMurtry and Scriven, 1964; 1965, 1966, 1968; McMurtry, 1977). Phytoseiids also feed on deciduous fruits in peach orchards (Putman and Herne, 1964, 1966), and other groups of arthropods, mainly Homoptera and Lepidoptera (McMurtry and Johnson 1965; Swirski et al., 1967, 1970; Knisley and Swift, 1971; van den Berg, 1985). Phytoseiids have also been found to feed on raspberry leaf rust and spores of powdery mildew (Chant, 1959; Knisley and Swift, 1971).

Fleschner and Ricker (1954) reported that Typhlodromus conspicuus (Garman) did not attack tetranychid mites, but Putman (1962) reported rearing the same species successfully on a diet of the European red mite (Panonychus ulmi (Koch)). Putman (1962) also reported that phytoseiid mites did not attack winter eggs of the European red mite, but Herbert (1959) found the same eggs to be destroyed by two species of phytoseiid mites, T. pyri and Typhlodromus corticis (Herbert). Similarly, Swirski et al. (1967) reported that about 61% of the young of Amblyseius swirskii Athias-Henriot attained adulthood in three different tests using all stages of the Green's mealybug (Pseudococcus citriculus Green) as food. But Ragusa and Swirski (1977) reported that A. swirskii did not develop or oviposit when fed the crawlers of the Green's mealybug or its eggs. Putman

(1962) pointed out that it was difficult to compare the consumption rates of the different species of phytoseiids because of varying experimental conditions.

McMurtry and Scriven (1964) reported that A. hibisci laid more eggs and developed faster when fed pollen as a food source than a tetranychid prey. But Lee and Davis (1968) found that the immature forms of T. occidentalis fed with pollen and apple foliage could not complete their development without spider mites as food; and the adult females would not lay eggs except when fed on spider mites.

McMurtry and Scriven (1964) further reported that addition of honeydew of Planococcus citri (Risso) to the diet of Panonychus citri (McGregor) enhanced the oviposition of A. hibisci and increased the percentage of young attaining adulthood. Ragusa and Swirski (1977) similarly reported that the addition of honeydew of Seissata oleae (Oliver) and P. longipinus Targ-Tozz to Tetranychus cinnabarinus (Boisduval) as prey raised the oviposition rate of A. swirskii. Blommers (1974) observed that addition of beehoney to Tetranychus neocaledonicus Andre as a diet improved considerably the egg laying ability of A. vazimba.

A phytoseiid can differ in its response to different food sources under the same experimental conditions such as was reported for A. umbraticus and A. citrifolius

(Knisley and Swift, 1971; De Moraes and McMurtry, 1981). Some phytoseiids such as Amblyseius potentillae (Garman), T. floridanus and T. occidentalis have been reported to show preference towards certain stages of their prey (McMurtry and van de Vrie, 1973; Tanigoshi and McMurtry, 1977; McMurtry and Flaherty, 1977).

1.1.7 Cannibalism

Many phytoseiids such as A. fallacis, T. caudiglans, Typhlodromus longipilus Nesbitt, M. occidentalis and T. occidentalis have been reported in the literature to go into cannibalism in the absence of their prey (Ballard, 1954, Burnett, 1971; Putman, 1962; Burrell and McCormick, 1964; McMurtry and Scriven, 1964; Laing, 1969; Croft and McMurtry, 1972). Some others such as T. cucumeris have been reported to go into cannibalism when the prey are present (El-Baldry and Zaher, 1961). Lee and Davis (1968) reported that T. occidentalis can starve to death rather than go into cannibalism. Laing (1969) reported that M. occidentalis attacked and consumed the young and the eggs of P. persimilis, but avoided prolonged contact with the adults.

1.1.8 Mortality

Mortality has been reported by several authors to occur at different stages of phytoseiid development. Chant (1963) reported that winter mortality is severe on adult phytoseiids. Chant (1960) reported that winter

mortality ranged from 90-95% in Southeastern England and results in low densities of predators in spring with consequent disadvantages from the control point of view. Blommers and Van Etten (1975) reported that a steady larval mortality was observed in all their mass rearings of A. bibens. Sabelis (1985) reported that mortality is rare among the young stages of phytoseiids.

1.2 Phytoseiid Biology on Artificial Diets

1.2.1 Artificial Diets for Insects

The use of artificial diets for rearing insects was developed mainly in the 1950s to meet the demand for large numbers of insects required for fundamental research in the fields of physiology, ecology, and genetics, and in insect control techniques such as male sterilization, pathogen production and biological control and integrated control programmes (Singh, 1977).

The first artificial foods for insects was reported by Bogdanov (1908) in which he reared Calliphora vomitoria axenically from egg to adult. His diet consisted of peptone, meat extract, starch, and minerals. Loeb (1915) successfully reared Drosophila sp. for five generations on the diet composed of grape sugar, cane sugar, ammonium tartrate, citric acid, dipotassium hydrogen phosphate, magnesium phosphate, and water.

Schultz et al. (1946) reared for the first time Drosophila melanogaster Meigen axenically on a chemically defined diet composed of pure amino acids, salts and vitamins.

The rearing of a phytophagous insect (Ostrinia nubilalis Hubner) on an artificial diet was first reported by Bottger (1942). This diet was compounded from casein, sugar, fats, salts, cellulose, agar, and water. This work was followed by that of Beck et al. (1949) whose diet was formulated from highly purified natural products, but containing an unidentified growth factor which was later identified as ascorbic acid by Chippendale and Beck (1964). Many subsequent investigators modelled their test diets on these two pioneer reports (Singh, 1977).

Ishii (1952) reared the Asiatic rice borer, Chilo suppressalis (Walker) and Matsumoto (1954) reared the oriental fruit moth, Grapholitha molesta (Busck) in Japan by including extracts of host plants in the diet developed by Beck et al. (1949) for Ostrinia nubilalis. Vanderzant and Reiser (1956) reared the pinkboll-worm, Pectinophora gossypiella (Saunders) aseptically on a diet with no plant extracts. Since then many phytophagous insects have been reared on diets compounded from pure chemicals and other nutritive substances (Singh, 1977).

1.2.2 Artificial Diets for Tetranychid Mites

Compared with insects very little attention has been given to mites, probably because of their seemingly lesser economic importance.

Brickhill (1958) cultured two species of tydeid mites on a paste of enzymatic protein hydrolysate, fructose and water.

Fritzsche (1960) made the first attempt to maintain spider mites on an artificial diet. His media consisted of sucrose, asparagine, aspartic acid, glutamine, glutamic acid, peptone, a vitamin mixture and mineral salts, as a watery solution.

In this medium, adult females of T. urticae transferred from bean leaves to the diet stayed alive for about twenty-one days, while the eggs they deposited on the membrane hatched. But the larvae which hatched from these eggs failed to moult towards the protonymph stage and eventually died.

Rodriguez and Hampton (1966) developed a holidic diet on which they reared the plant feeding mite (T. urticae) from egg to adult.

Their diet contained a large amount of amino acids, several lipid compounds, a vitamin mixture, mineral salts, RNA and sucrose.

The composition of the amino acid mixture as reported by van der Geest (1985) was based on an analysis of bean leaves as a result of a preliminary investigation by Rodriguez (1964). Rodriguez and Hampton (1966) used a higher concentration of amino acid mixture in their diet. When the mites fed on this diet with glucose-U-C^{14} added to it and subsequently analysed, high radio-activity was found in the following compounds: alanine, aspartic acid, cysteic acid, cystine, glutamic acid, glycine, proline, serine, and threonine. These amino acids could be synthesized by the mites from glucose and, therefore, were not essential in their food (van der Geest, 1985). But low or no radio-activity was found in arginine, histidine, isoleucine, lysine, methionine, phenylalanine, tyrosine, and valine, indicating that these amino acids were essential since the mites could not synthesize them from glucose.

In 1969 Rodriguez presented a holidic diet which differed from that developed by Rodriguez and Hampton (1966). His diet contained a much lower concentration of the lipid fraction and a higher concentration of sugars. He chose a lower level of lipids because of the observation that egg production by females on a diet with low content of lipids was much higher.

Mites were also cultured by Bot and Meyer (1967), Matsumoto (1968), Pillai and Winston (1968) and Rodriguez and Lasheen (1971).

Ekka et al. (1971) used the diet formulated by Rodriguez (1969) to study oviposition and egg viability of T. urticae reared on it. They made slight alterations in the composition by omitting cholesterol and adding vitamin E. They reported that a lower concentration of fatty acids in combination with a higher content of plant sterols resulted in a higher egg production (0.64 eggs per female per day) and an egg viability of about 20%, in contrast to results obtained with the original diet of Rodriguez in which egg production was 0.34 per female per day, and an egg viability of 3.6%. With Ekka et al.'s (1971) diet, results further indicated that the preoviposition period shortened from 3.5- to 1.5 days.

Another attempt to develop artificial diets for the spider mites was made by Storms and Noordink (1972) using the diet developed by Rodriguez (1966). The concentration of amino acids in their medium was much lower (0.14% instead of 2%). This was more a reflection of the actual concentration in bean leaves (0.06%) (van der Geest, 1985). Egg production was higher than reported in previous studies and amounted to about 2.25 eggs per female per day. Although mites were kept alive on this diet for about twenty-one days, no development from egg to adult was obtained.

The only first successful culture of spider mites on an artificial diet for more than one generation was reported by Bosse et al. (1981). Their diet contained crude materials such as casein and wheat germ, and was described as a meridic diet (van der Geest, 1985).

A meridic diet was described by Singh (1977) as that composed of a holidic base to which at least one substance or preparation of unknown structure or uncertain purity has been added, whereas a holidic diet is one in which the constituents other than purified inert materials are of exactly known chemical structure before compounding. The development of T. urticae on the diet developed by Bosse et al. (1981) was reported to take approximately longer time compared to those fed on bean leaves, while egg production of the first generation was only about 1.5 eggs per female per day in contrast to phaseolus leaves on which egg production may be as high as 7-8 eggs per female per day (van der Geest, 1985).

1.2.3 Artificial Diets for Phytoseiid Mites

While many artificial diets have been developed for insects few have been tested on predaceous mites (Singh, 1977). McMurtry and Scriven (1966) tested the oviposition rate and development of immature stages of four phytoseiids on several artificial diets composed of:

- Sucrose (2%)
- Sucrose + yeast hydrolysate (20 + 20%)

- Molasses (20%) and
- Molasses + yeast hydrolysate (20 + 20%).

In these diets both sucrose and molasses increased survival of adult females of A. limonicus and A. hibisci, T. occidentalis and T. rickeri. However oviposition rates were low and the development of immature stages was poor compared to mite prey or pollen. Although the results were poor, they suggested that artificial diets could be developed, particularly for species having polyphagous habits (McMurtry and Scriven, 1964).

Shehata and Weismann (1972) obtained viable eggs from P. persimilis when fed on the following three artificial diets:

Diet 1 comprised

- Honey (15g)
- Ascorbic acid (100 mg)
- Vitamin complex (300 mg)
- Antiseptic (1 ml)
- Pangamin extract (50 mls), and
- Distilled water (100 mls).

Diet 2 had the same composition as diet 1 except that only 50 mls of vitamin extract was used.

Diet 3 had 5 mls of distilled water added to 10 mls of diet 2 and mixed well. To this solution 40 mg of different amino acids were added. The development of

immature stages was reported to have been obtained with these diets, but the resulting female adults failed to produce viable eggs. They were smaller in size and had shorter life span than predators fed on natural mite prey.

Kennett and Hamai (1980) tested nine phytoseiid species on an artificial diet composed of:

- Bee honey (5g)
- Sugar (5g)
- Food yeast flakes (5g). (The G. and R. Rose Brand Rodeo California)
- Yeast hydrolysate (6 gm) (Ardamin pH) (Yeast Products Incorporated, New Jersey)
- Enzymatic casein hydrolysate (US Biochemical Corp. Cleveland, Ohio)
- Fresh egg yolk (10g), and
- Water (68 mls)

The nine phytoseiids tested were:

A. hibisci, A. largoensis, A. limonicus, Typhlodromus arboreus (Chant), T. pyri, I. degenerans, P. persimilis, M. occidentalis, and Metaseiulus pomoides Schuster and Pritchard.

P. persimilis and M. occidentalis did not oviposit on the artificial diet, but the rest seven mite species oviposited normally. Generally the predator cultures maintained on the artificial diet showed a gradual

decline in viability (Kennett and Hamai, 1980). The immature stages of the species that oviposited failed to develop in subsequent generations.

Ochieng et al. (1987) reported the development of a unique artificial diet "ICD 286" which sustained Amblyseius teke (Pritchard and Baker) up to 32 generations.

Their diet composition comprised:

- Egg yolk (30g)
- Honey (10g)
- Milk powder (Lactogen) (10g)
- Wesson's salt (1g), and
- Distilled water (50 mls)

This was the first time an artificial diet was reported to sustain a phytoseiid mite for 32 generations at the time of this report (Ochieng, Pers. Comm.).

2. MATERIALS AND METHODS

2.1 Maintenance of Stock Culture

Neoseiulus idaeus was reared in the laboratory at room temperature on a diet of red spider mites (Tetranychus spp.) (Acarina: Tetranychidae). It was obtained through Commonwealth Institute of Biological Control (CIBC) Kenya.

Bean leaves (Phaseolus vulgaris L.) containing all stages of the red spider mites were placed upper side down in plastic rearing boxes (16 x 10 x 6.5 cm) containing water saturated cottonwool at the bottom. These rearing boxes were shaded with a black linen material and covered with a plastic lid which had a large opening at the centre for ventilation (Plate 1). All the stages of the predator were reared on these bean leaves containing the prey.

The rearing boxes were examined daily and water was added into them when necessary to keep the cotton-wool moist. The bean leaves were changed every two to three days with new leaves containing abundant prey by placing the old leaves on top of the new ones so that the mites could transfer to the new leaves. After a day the predators in the old leaves which had not transferred to the new leaves were picked with a camel hair brush (NO.oo) and transferred onto the new leaves. This was

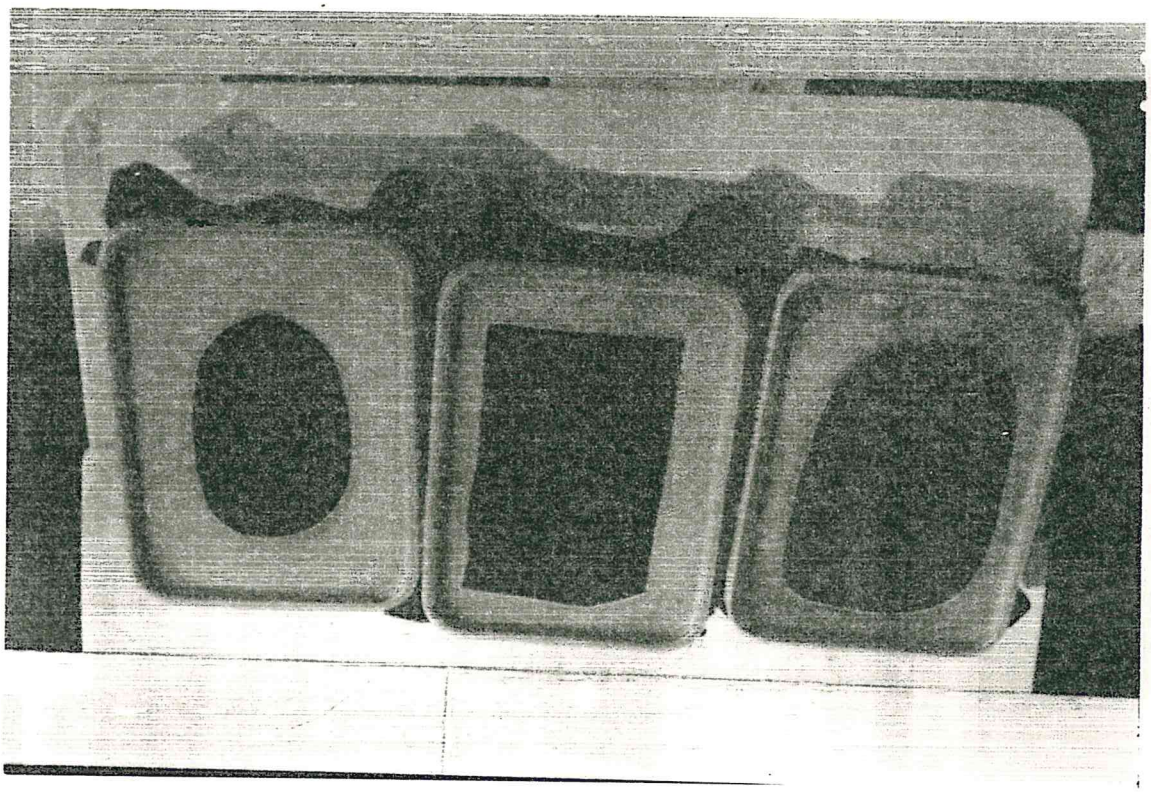

Plate 1. Plastic rearing boxes containing bean leaves for rearing Neoseiulus idaeus

necessary to ensure that all the predators transferred fully to the new leaves with abundant prey, because if left to transfer fully on their own some of them migrated back to the old leaves. This habit was observed several times hence it became necessary to transfer them manually with the aid of the camel hair brush. In this way the stock culture was maintained throughout the experimental period.

2.2 Rearing of the Red Spider Mites (Tetranychus spp.)

The red spider mites were raised on bean plants (P. vulgaris) in the screenhouse in plastic buckets containing humus soil (Plate 2). Water was added daily to the buckets to keep the soil moist for the healthy growth of the plants. Occasionally a nutrient solution was added to the water and sprinkled into the buckets to provide additional nutrients to the plants.

Fresh beans were planted every ten days by sowing the seeds 2 cm deep in the soil in the buckets. Seven to twelve days after plant emergence red mites were transferred to them by using camel hair brush to pick the mites singly from the old culture to the new leaves. In this way prey abundance was maintained to feed the predators throughout the experimental period.

Plate 2. Plastic buckets containing bean plants for rearing the red mites (Tetranychus spp.)

2.3 Arenas of Bean Leaves (P. vulgaris)

Experiments were conducted using arenas of excised pieces of bean leaves (P. vulgaris) 3 cm in diameter placed upper side down on water saturated cottonwool in plastic petridishes 9 cm in diameter and 1.5 cm in depth. These were placed in Melamina Geostyle plastic trays measuring 41 x 28 x 1.9 cm containing water up to 1 cm deep (Plate 3).

The plastic petridishes were perforated at the bottom so that the cottonwool in them could absorb water from the tray through these perforated ends to keep moist and prevent escape of the predators.

The leaves were changed every two to three days, and the predators were manually picked and transferred to the new leaf discs containing the prey. Water was added daily to the tray to maintain sufficient water level.

Changing of the leaves every two to three days was necessary because if the leaves became old the red spider mites escaped and walked into the water barrier and got drowned. On the other hand the appearance of the predators particularly the juvenile forms indicated that they did not seem to derive sufficient nutrients from the prey if the leaves were old.

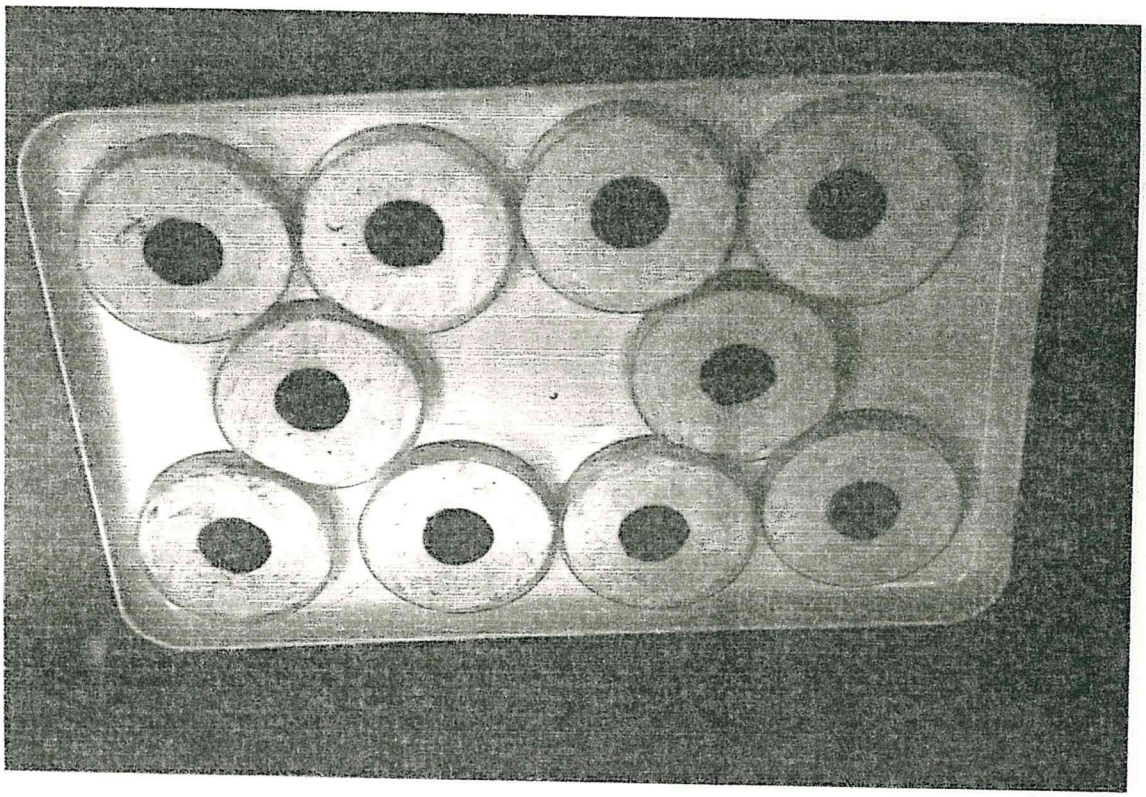

Plate 3. Petri dishes containing bean leaf discs with mixed stages of the prey for Neoseiulus idaeus.

2.4 Arenas of Thunderbird Cups (=medicine cups).

Experiments were also conducted using thunderbird cups (Plate 4) placed upper side down in rearing boxes containing water-saturated cottonwool. Artificial diets were introduced at the base of these cups (Plates 5 and 6). The cups were firmly fixed to the bottom of the rearing boxes with plasticine. The plasticine was also attached at both sides of the cups to provide a rough surface for oviposition. The edges of the cups were lined with talcum powder or vaseline in latter experiments to prevent escape of the predators.

Composition of the Artificial Diets

Liquid Diet

The liquid artificial diet "ICD 286" was developed by Ochieng *et al.* (1987) on which they reared a native phytoseiid mite, *A. teke* for several generations. This diet was compounded from the following ingredients:

- Egg yolk (30 g)
- Milk powder (Lactogen) (10g)
- Bee honey (Commercial) (10g)
- Wesson's salt (1g)
- Distilled water (50 mls)

These ingredients were properly mixed using a blender to a homogeneous consistency and dispensed with a 5 ml disposable syringe (1 ml) into the base of the

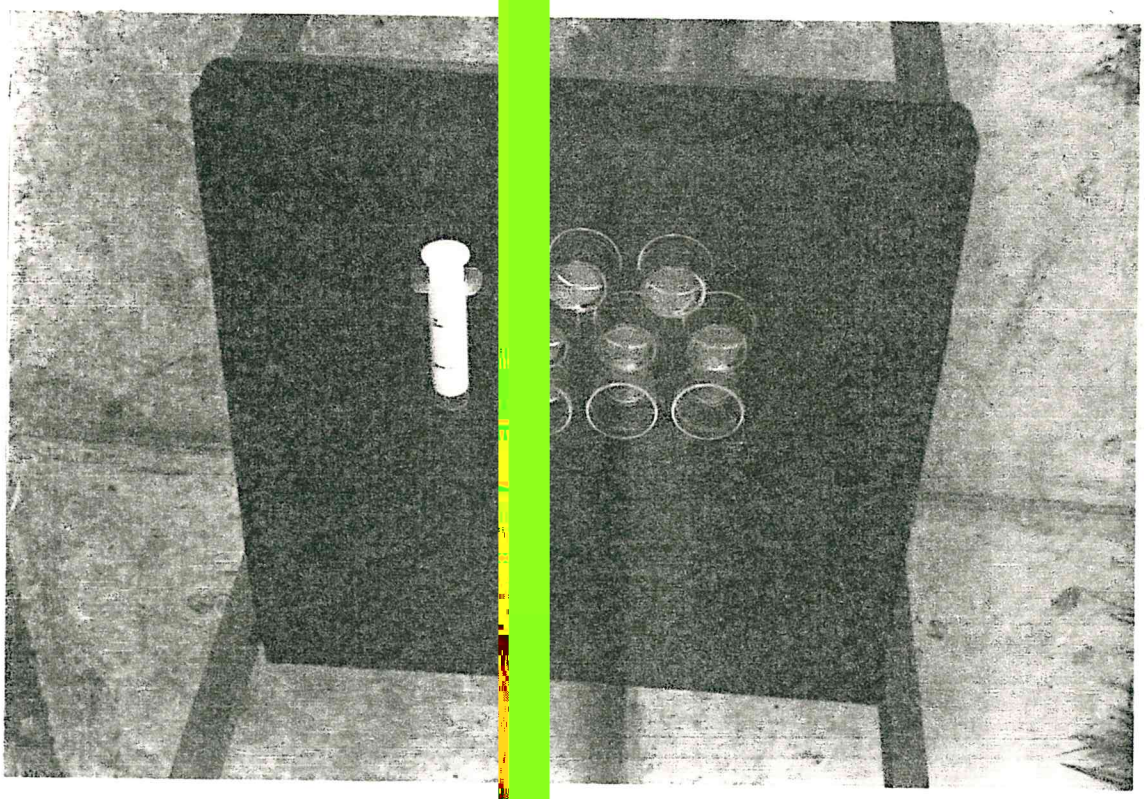

Plate 4. Plastic Thunderbird cups used in dispensing artificial diets.

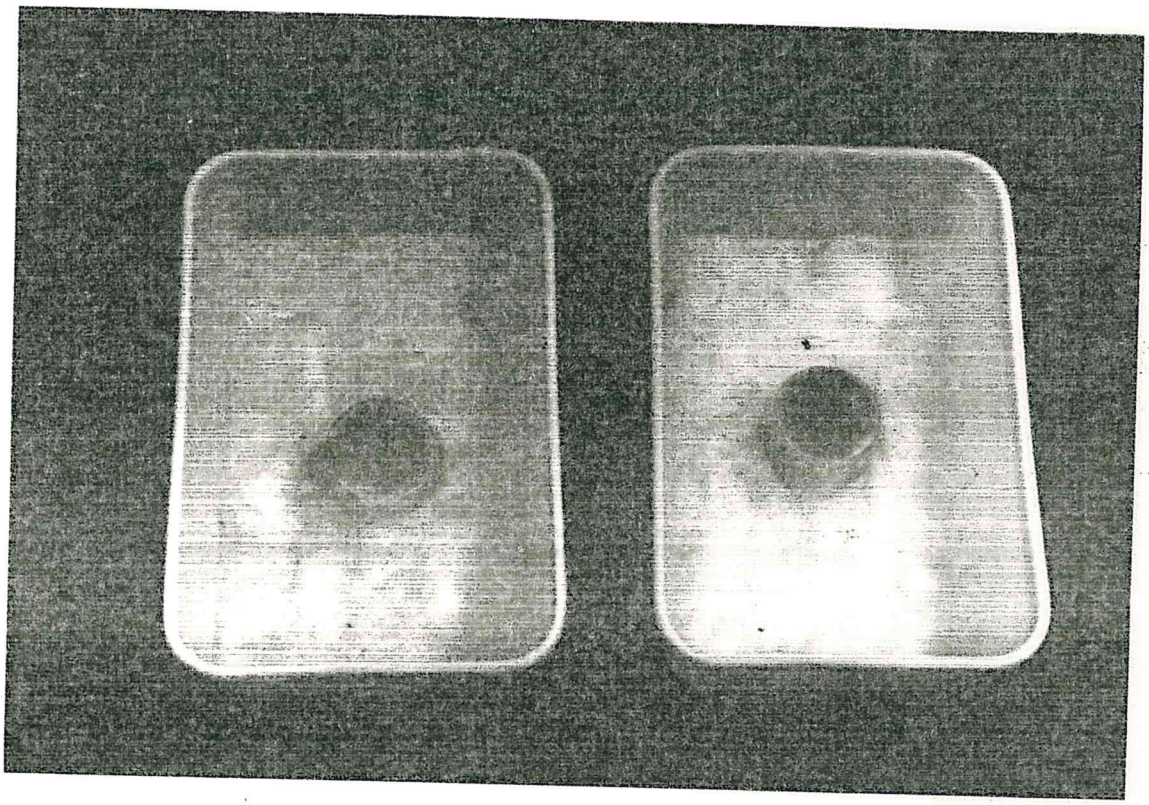

Plate 5. Plastic rearing boxes containing artificial liquid diets.

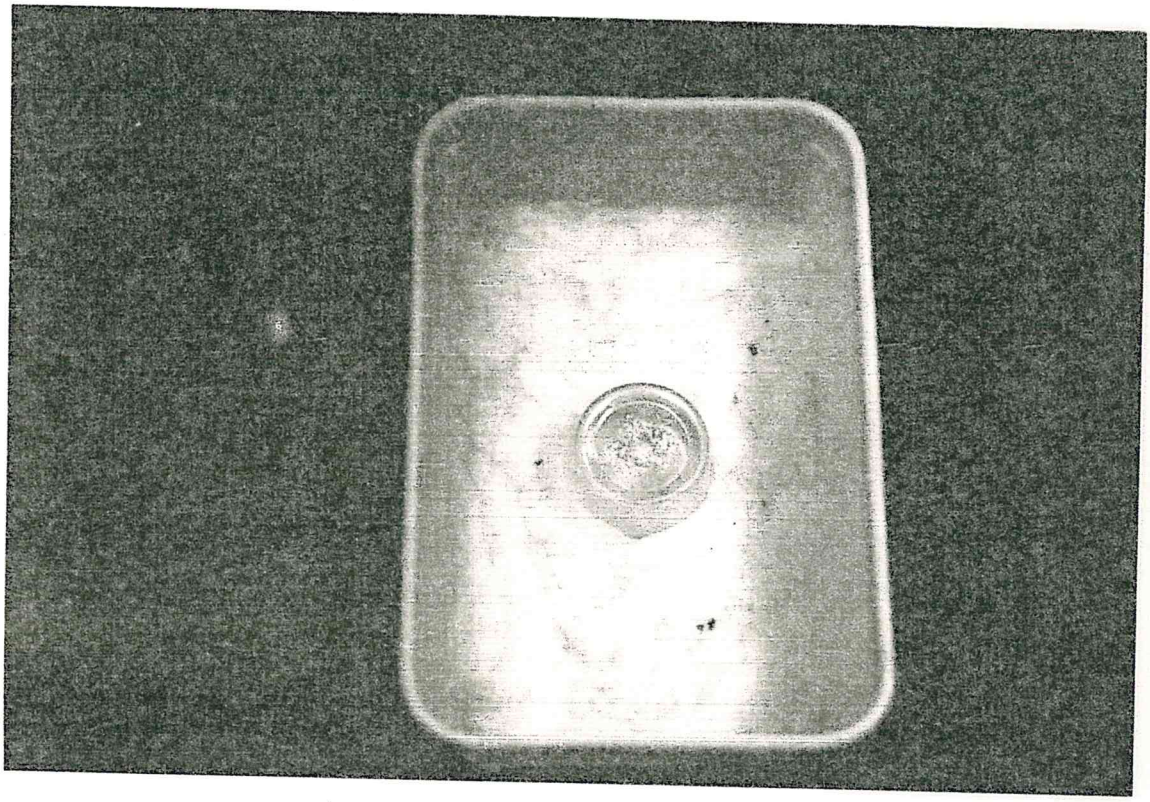

Plate 6. A plastic rearing box containing artificial solid diet.

thunderbird cups. Parafilm M. was stretched over them to serve as a thin membrane through which the predators could feed.

The solid diet was compounded from the same ingredients as for the liquid diet except that in place of honey sugar was used and there was no water added as shown below:

- Egg yolk (30g)
- Milk powder (Lactogen) (10g)
- Sugar (10g)
- Wesson's Salt (1g)

The ingredients were also thoroughly mixed in a blender to a homogeneous consistency. These were dispensed into the base of the thunderbird cups with spatula. The diet was left bare in the cups with no parafilm M. stretched over them as for the liquid diet (see Plate 6).

All experiments were set in a temperature controlled room ($27^{o}C$) and a relative humidity of 80% except otherwise stated.

2.5 Life Cycle and Development

The life history of N. idaeus was studied on three diet forms:

- Natural diet (red spider mites, Tetranychus spp.), Liquid Artificial diet, and Solid Artificial diet.

Fifty to one hundred adult females of N. idaeus were isolated into petridishes containing bean leaves with abundant prey (Plate 7). Thirty to fourty adult males were later introduced so that the females could lay eggs. The petridishes were either put in rearing boxes or plastic trays with water to keep the cotton-wool in the petridishes moist in order to prevent escape of the mites and also to prevent the leaves from drying up.

The petridishes were observed once every hour with a view to determining the specific age of the eggs. The eggs laid were picked with a camel hair brush and placed singly into each of ten petridishes containing leaf discs (see Plate 3). The petridishes were placed in trays containing water and taken to the controlled room. The same procedure was used for the artificial diets. Eggs were also placed singly into each of 20 rearing boxes with thunderbird cups containing artificial diets. The rearing boxes were covered with black-linen cloth and also kept in the controlled room. Ten of the rearing boxes contained artificial liquid diets and the other ten contained solid artificial diets.

The three experiments were set up simultaneously. The development of N. idaeus on the natural diet was to be compared with that on the artificial diets.

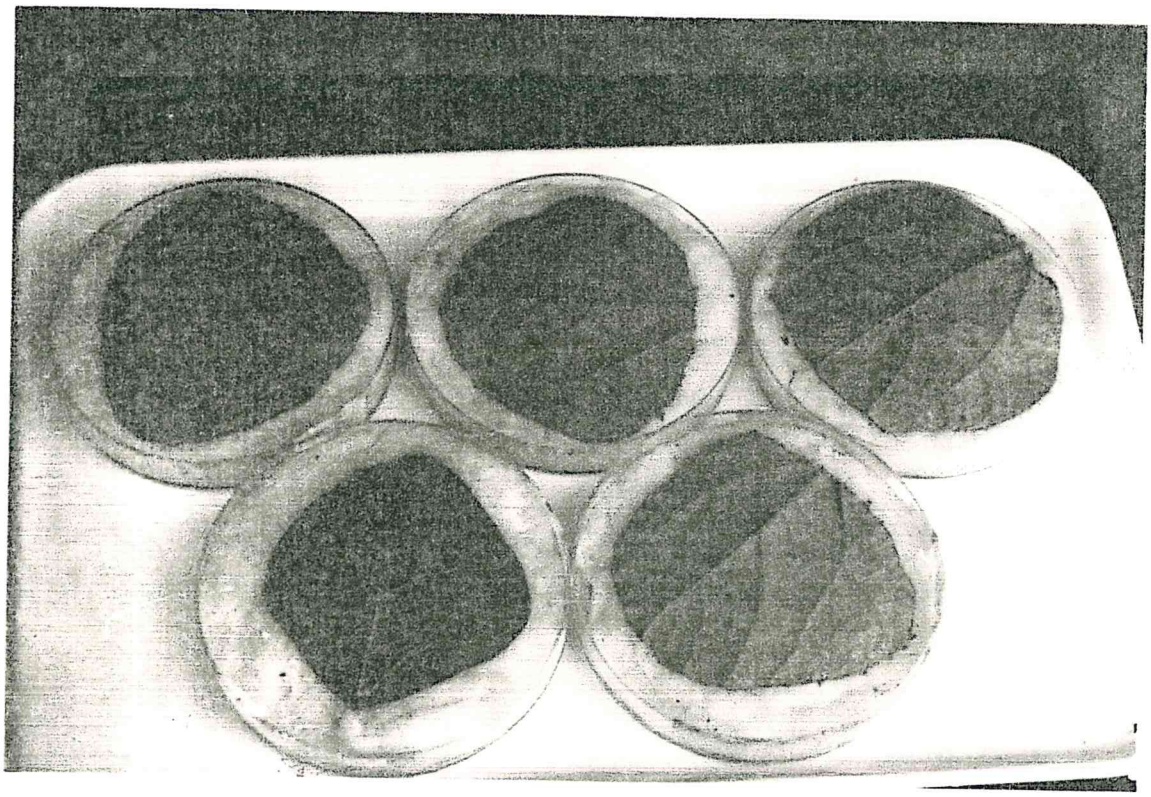

Plate 7. Plastic petri dishes containing bean leaves.

Observation: After twenty four hours, observations were made once every two hours, and at times continuously until all the eggs had hatched. Time (in hours) was recorded for each petridish and thunderbird cups. The average hatching time was recorded for each feeding medium. The experiment was repeated six times for each diet type.

For the larval development up to the protonymph stage observation was made once every three hours for the first nine hours and there after once every thirty minutes to one hour until all the larvae had moulted to the protonymph stage.

For the development of the protonymph through to the adult stage, observations were made every three hours for the first twelve hours and thereafter once every two hours. Sometimes observations continued uninterrrupted until development to the adult stage had been completed.

These time intervals were chosen on the basis of preliminary investigations on the developmental periods of the predator from the eggs to the adult stages when it was established that no eggs were observed to hatch before twenty-four hours, and larval moulting took place from ten hours upwards; and for the other stages from fourteen to sixteen hours. These preliminary observations were responsible for the system of observation described above.

For the preoviposition period adult males from the stock culture were introduced to the females at the deutonymph stage. As soon as the mites moulted to the adult stage, observation was made once every two hours and at times continuously until all the mites had oviposited for the first time in each petridish. This constant observation was necessary to determine the mating time after complete moulting to the adult stage and the time interval between the first time of mating and oviposition. Thus from this close observation the developmental time of the predator (Egg - to - egg) was determined.

2.6 Measurements of the Various Life Stages

The eggs were measured directly from the leaves on Wild Heerbrugg M5A dissecting microscope with a stage micrometer attached. The unit of measurement was taken from the squares on a graph paper placed under the microscope. Under magnification 10 x /21 x 25 (i.e. eye piece - 10 x /21, nosepiece = 25), 65 units from the microscope was equivalent to one square of graph-paper which is equivalent to 1 mm. Therefore, whatever measurement that was obtained was divided by 65 units to give 1 mm both for the lengths and the widths of the eggs. A total of twenty eggs were measured.

For the larval stage up to the adult stages it was difficult to get a clear distinction under the dissecting

microscope between the gnathosoma which bears the false-head comprising the palpi, the chelicerae and the stylets; and the idiosoma which bears the walking appendages. The gnathosoma was, therefore, excluded from the measurements of the lengths of the body.

The widths of the larval stages were measured between legs two and three, while for the eight-legged stages it was between legs three and four. These areas show the maximum width of the body.

To carry out these measurements, the predators were mounted on slides with Hoyers solution and measured under a Phase - Contrast microscope Leitz - Orthoplan (Model, 1986) under magnification 10 x.25. The standard unit of measurement was: 1 unit equivalent to 5.15 millimicrons. Twenty N. idaeus specimens of each stage were measured. The length of the idiosoma was measured.

2.7 Mounting of Specimens

Specimens were mounted on microscope slides size 25.4 x 76.2 mm (1" x 3"), and 1 mm to 1.2 mm thick, in Hoyer's solution.

The predators were picked with an improvised micropin and placed on a drop of Hoyer's solution on the microscope slide. This was covered with a square piece of cover slip 26 x 26 mm, or a round cover slip 22 mm - or 16 mm diameter depending on which one was available at the time of the slide preparation.

Different sizes of the cover slips were used during the period of the slide preparation.

The slides with the cover slips were heated gently over a spirit lamp to fix the mites and to straighten the appendages, namely the palpi, the chelicerae, the stylets and the walking legs as well as to clear the Hoyer's solution. They were examined under a compound microscope using a magnification of x 40. The slides were stored in an oven with a temperature of between 30°C and 50°C and left for about ten to fourteen days to dry. They were then taken out, ringed with a neutral nail polish and stored in slide boxes.

2.8 Drawing

Drawings of the different mite stages (see Figures 1-6) were made with the aid of camera lucida attached to Wild Laborlux 12 compound microscope. Leg IV was drawn separately to show the macroseta on the basitarsus which distinguishes the genus Neoseiulus from the other genera of phytoseiid mites (Figure 7). The ventrianal shields of both sexes were drawn separately to facilitate microscopic examination for distinguishing between male and female specimens (Figures 8 and 9). Also separately drawn was the false head bearing the palpi, the chelicerae and the stylets (Figures 10 and 11). Effort was made as far as was possible to show the visible body setae.

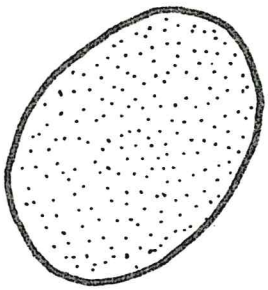

Fig. 1. The egg stage of N. idaeus. x100.

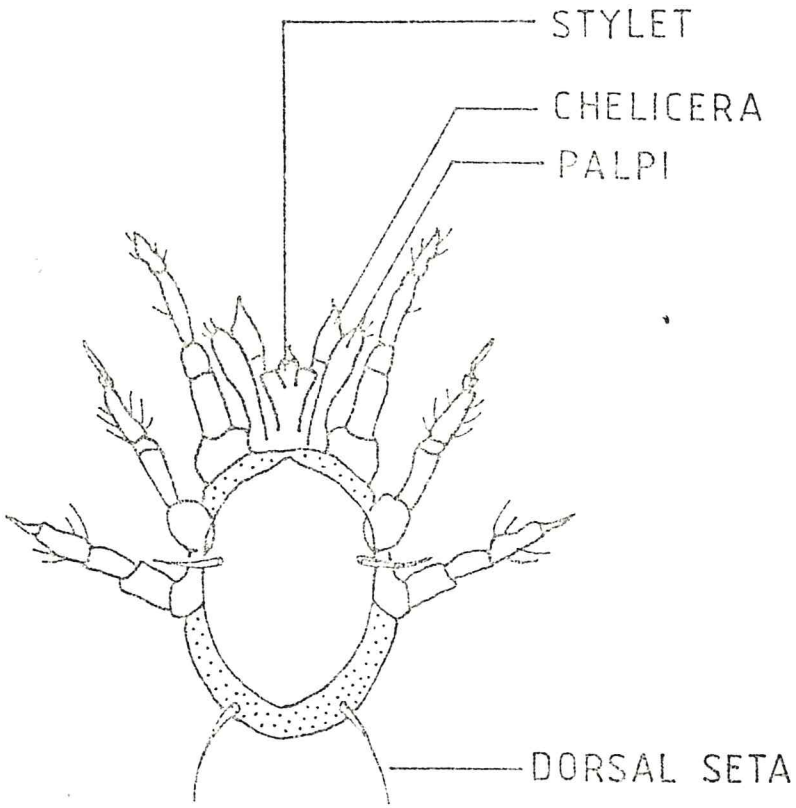

Fig. 2. The larval stage of Neoseiulus idaeus x 100.

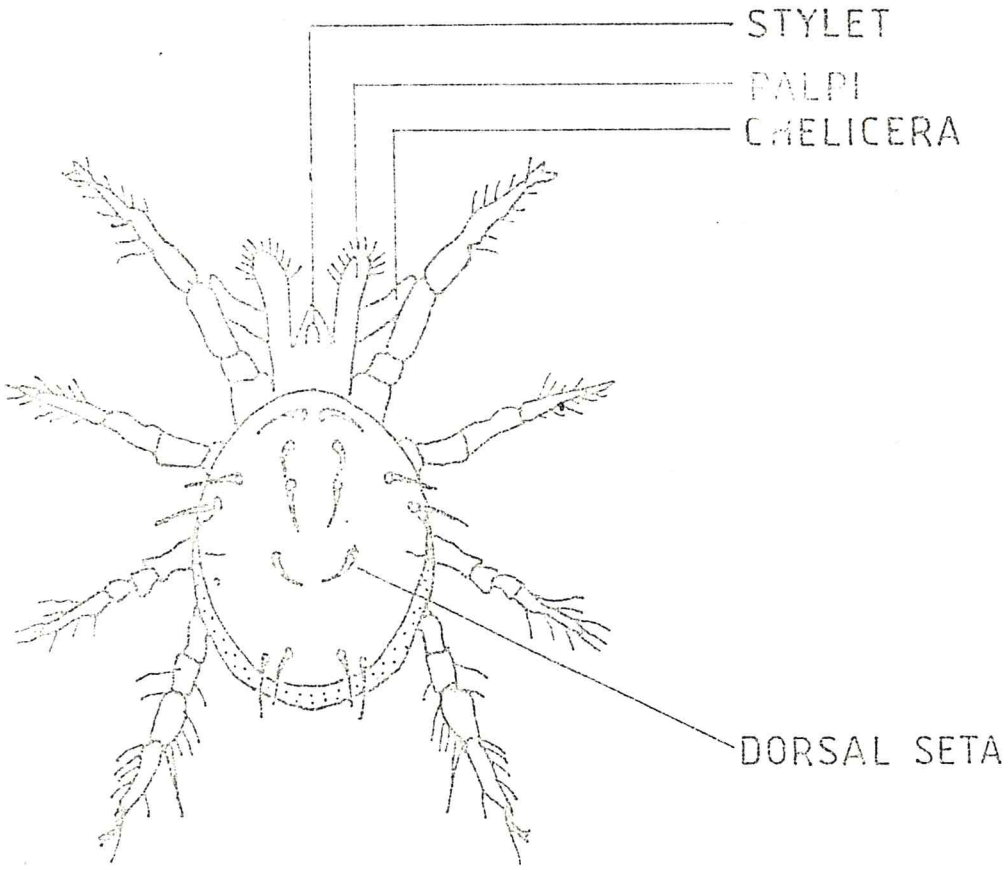

Fig. 3. The protonymph stage of Neoseiulus idaeus x 100.

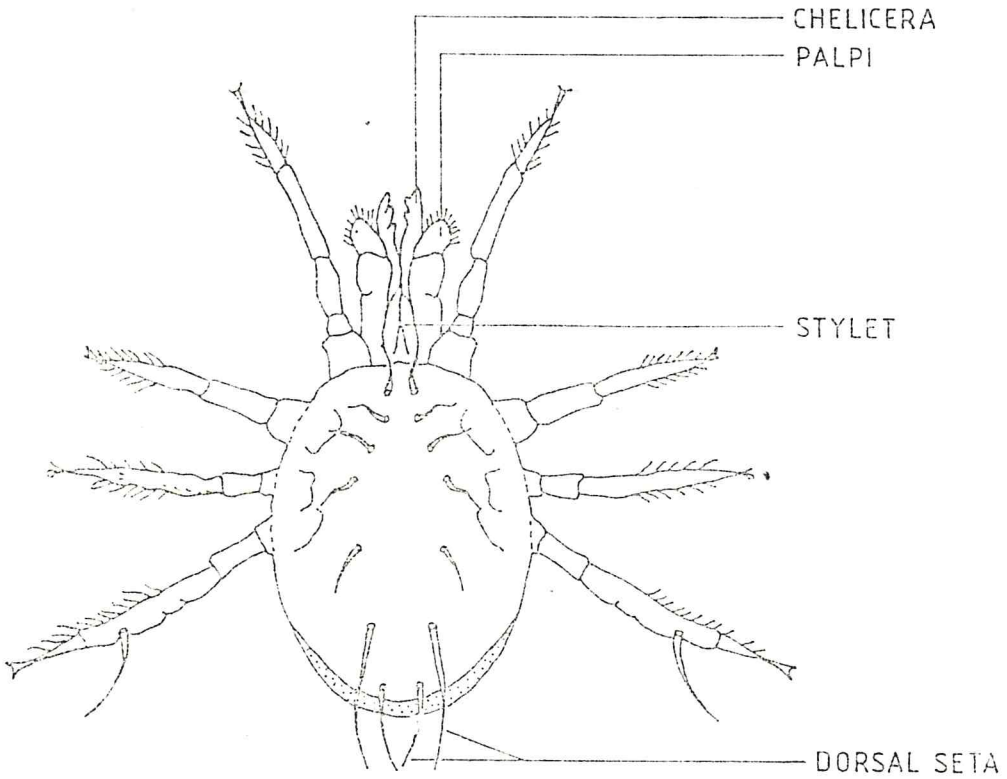

Fig. 4. The deutonymph stage of Neoseiulus idaeus x 100.

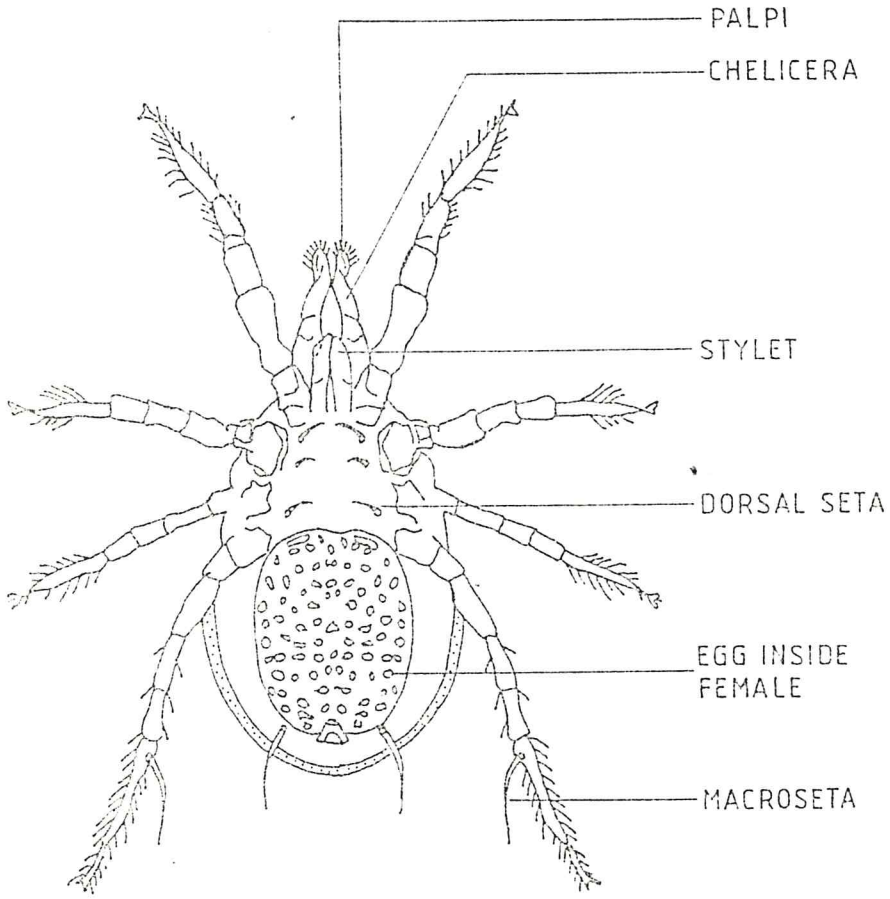

Fig. 5. The adult stage of female Neoseiulus idaeus x 100.

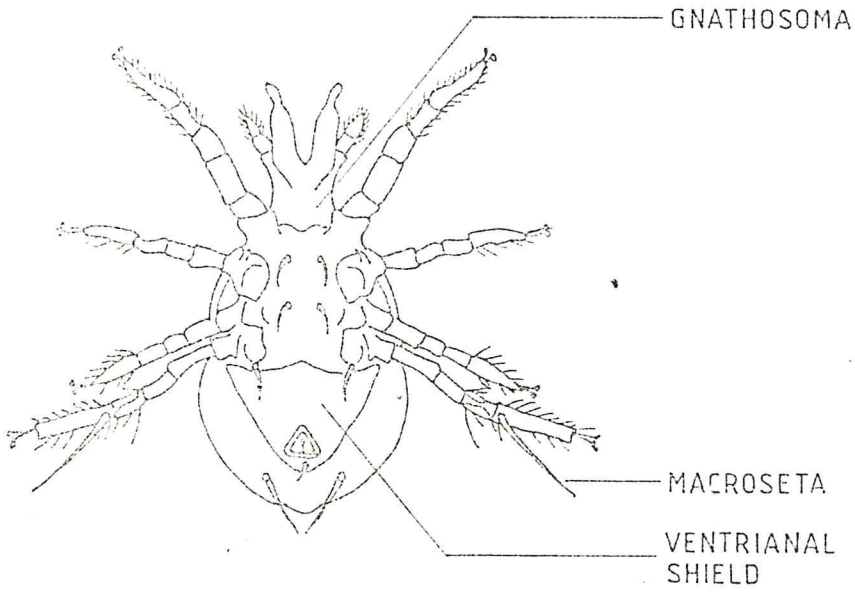

Fig. 6. The adult male of Neoseiulus idaeus x 100.

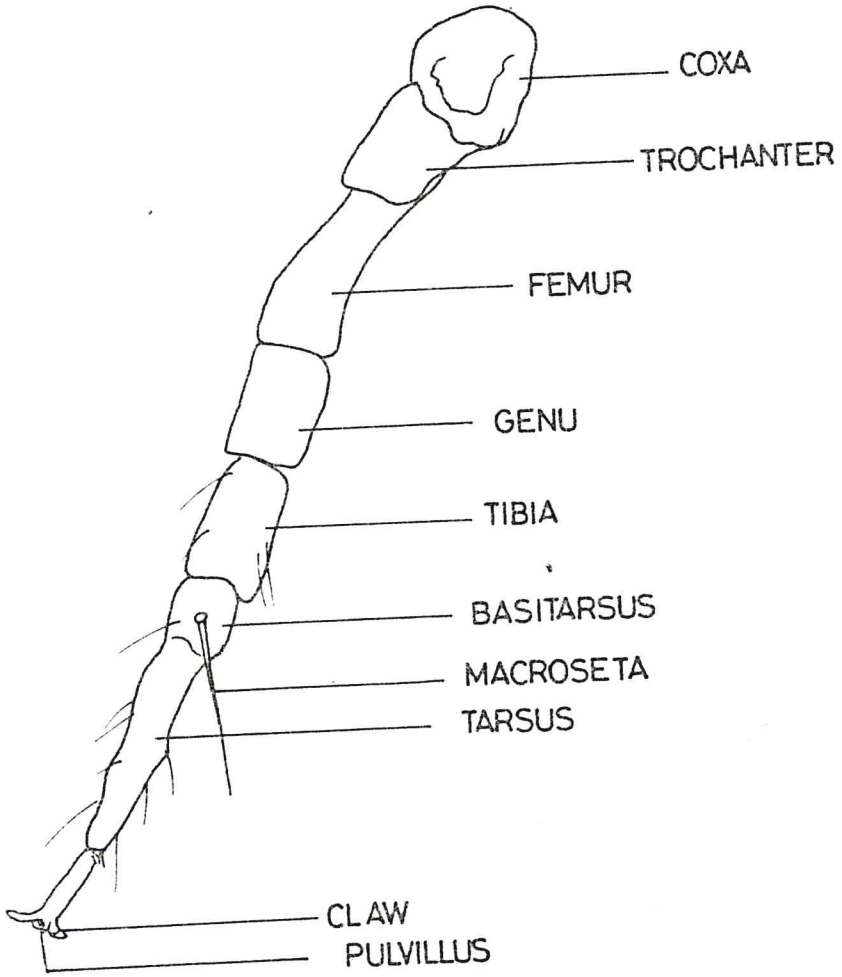

Fig. 7. Leg iv of N. idaeus. x250

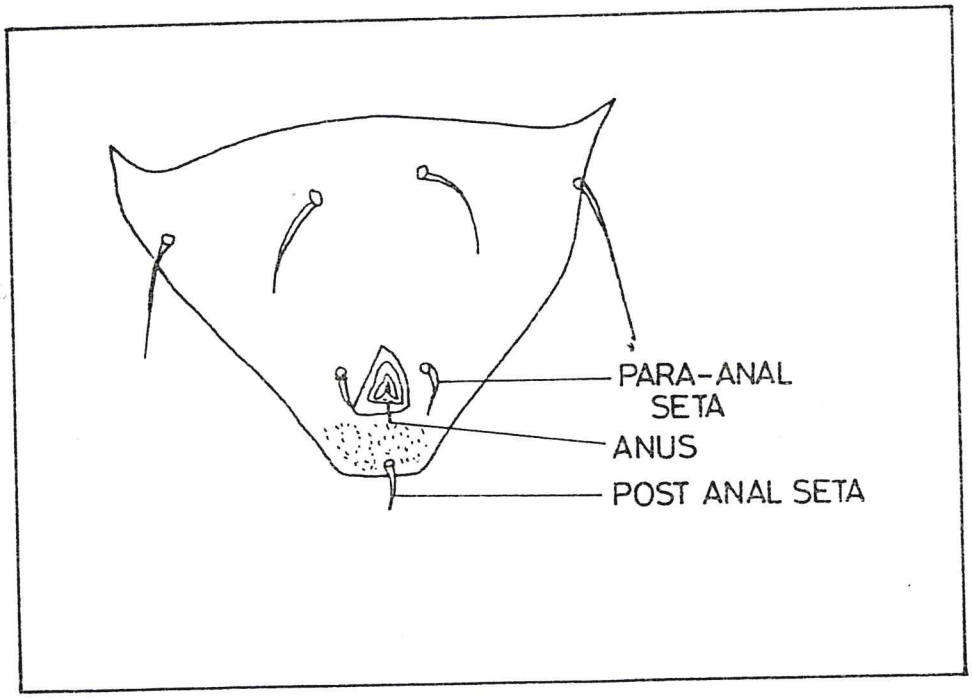

Fig. 8. Ventrianal shield of male N. ideaus. x250.

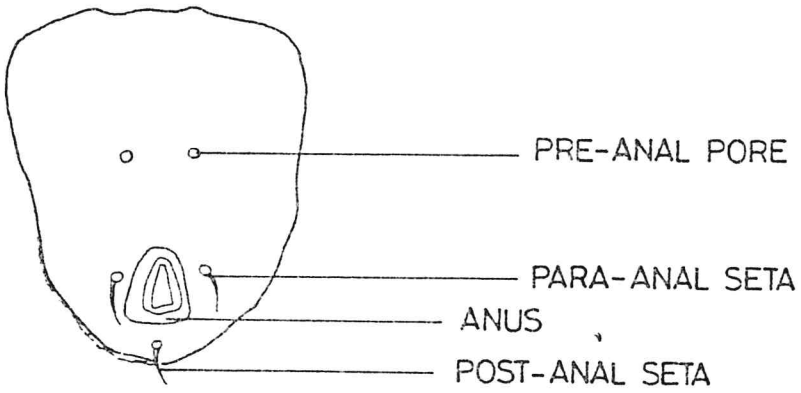

Fig. 9. Female ventrianal shield of N. idaeus. x250.

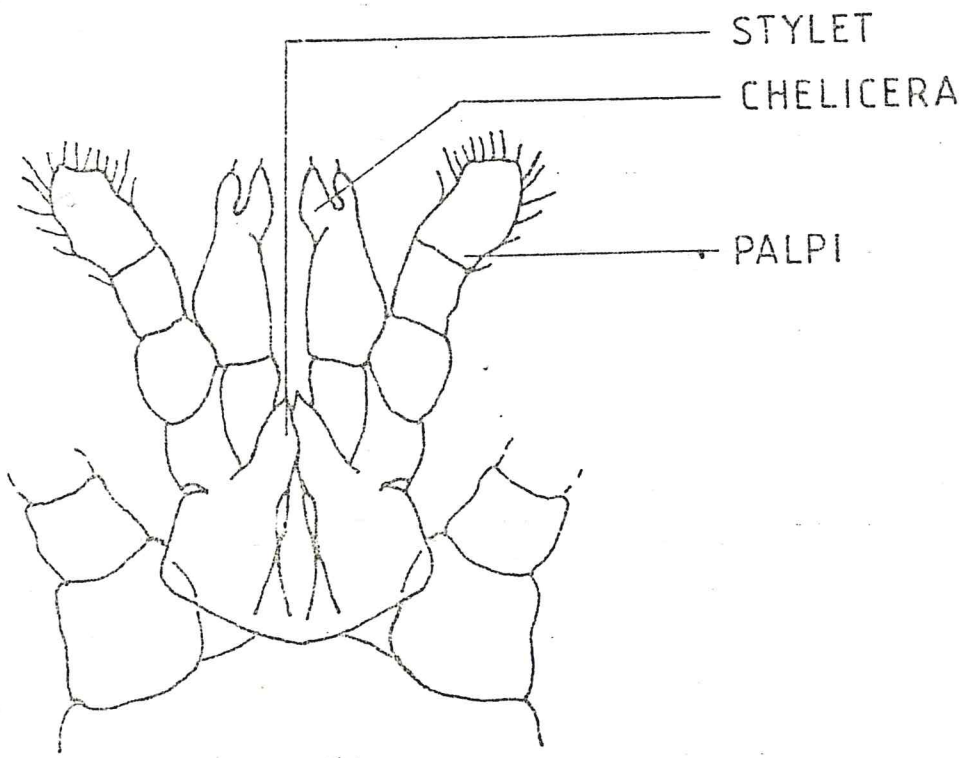

Fig. 10. Female gnathosoma x 250

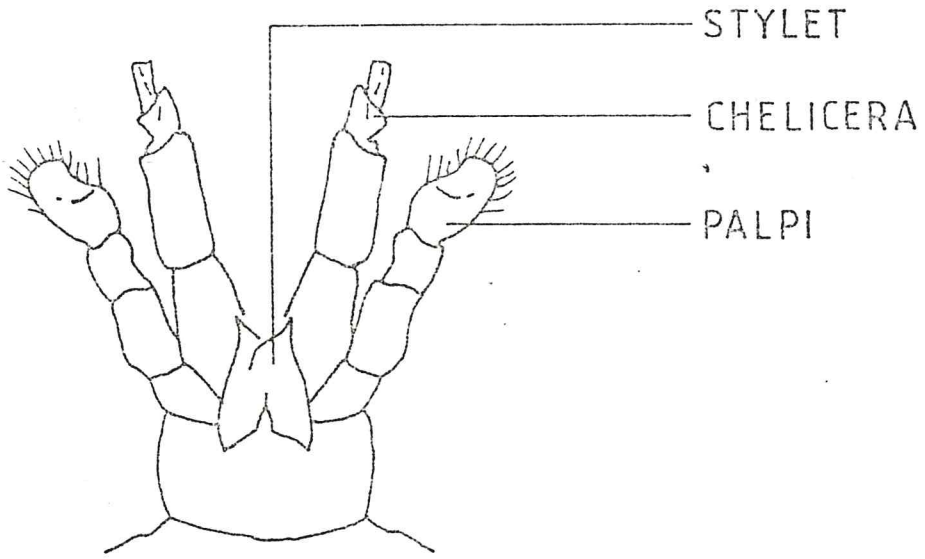

Fig. 11. Male gnathosoma. x 250

2.9 Fecundity and Sex Ratio

For this experiment the predator larvae were isolated and placed singly on each of eighteen leaf discs containing abundantly mixed stages of the prey and placed in petridishes containing water - saturated cottonwool. These were placed in a plastic tray containing water and kept in the controlled room as was described for the life stages. When the predators moulted to the adult stage, males were introduced unto the females from the stock culture and fecundity was recorded of each mite per leaf disc in each petridish.

During the first day of oviposition four of the predators died without laying eggs. These were excluded from the analysis. Two other experiments were conducted. In one, ten adult females were used. One of these did not lay eggs and died after seven days. This was also excluded from the analysis. In the next one, 5 females were used, and the experiment was terminated after 11 days.

For the study of the sex ratio eggs laid by individual females each day were removed into separate petridishes containing leaf discs and reared to adult stage wherefore the different sexes were recorded. This record was maintained throughout the egg laying period until the mites had either died or laid their full complement of eggs.

On the artificial diets the predators could not develop beyond the protonymph stage. Because of this, another experiment was set up separately in which deutonymphs from the stock culture were isolated in each of the feeding media. Ten female deutonymphs were used for each of the set ups. Males were also introduced unto these females from the stock culture. When the mites moulted to the adult stage, observation was made on preoviposition and fecundity.

2.10 Mating Behaviour and Parthenogenesis

To determine whether parthenogenesis occurred in N. idaeus, twenty female deutonymphs were isolated singly from the stock culture into each of twenty leaf discs in petridishes as was described for the leaf disc method. When the mites moulted to the adult stage, males were introduced to ten of such discs while ten were left without males.

Observation was made daily for six days to determine if the unmated females would oviposit.

2.11 Longevity

Longevity studies on the three diets were conducted using more than three hundred adult females and one hundred adult males from the stock culture isolated on leaf discs containing abundant prey. After twenty-four hours the eggs laid were collected and reared to the adult

stage. Five unsexed newly emerged adults were placed on each of ten leaf discs and for the artificial diets on the thunderbird cups. Another set of ten clean leaf discs with no food was also set up including a new modified diet. The objective was to compare the longevity of these mites on natural diet, artificial liquid diet, artificial solid diet, a no-food situation and a modified diet. These experiments were set up simultaneously.

Experiments were also set up at the same time with only the artificial diets to compare the longevity of these mites when confined on the diet with Talcum powder, Vaseline, and without any confinement.

Observations were made at the same time everyday to record the numbers of predators seen alive each day until all the mites had died or escaped.

The thunderbird cups were sealed at the edges with vaseline to prevent the mites from escaping and getting drowned in the water barrier. All the experiments were set up in a controlled room as was previously described.

For the analyses of all data references were made to Zar (1974), Wahua (1985), and Parker (1986).

2.12 Feeding Behaviour

The larval stage of the predator was used to start this experiment. Ten N. idaeus larvae were isolated

singly into each of ten clean leaf discs. Ten prey eggs were introduced into each of the discs. Continuous observation was made on the feeding habits and prey consumption rate of the larvae until they were in their quiescent stages.

The same procedure was repeated when the different stages of the prey were introduced as food.

The same feeding process was repeated in respect of the protonymphs of the predator and all the other stages as was done for the larvae except that observations were made after sixteen to twenty hours by which time the mites were in their quiescent stages to record the number of prey consumed before moulting into the next stage took place. With the adult predators observation was made after twenty-four hours to record the number of prey consumed.

2.13 Cannibalism

To observe whether cannibalism took place in this species, ten adult female N. idaeus were put singly into each of ten clean leaf discs. Ten adult males were also put singly into another set of ten discs. Three eggs of the predator were introduced into each of the discs. The predators were starved for about five hours in the discs before their own eggs were introduced as food. Observation was made after twenty-four hours to see if the eggs had been consumed. The same number of eggs were intro-

duced to another two sets of ten predators each. Similar observation was made after twenty-four hours.

Three larvae and three protonymphs of the predator were also introduced into each of the discs containing separately the adult males and females of the predator. Observation was also made after twenty-four hours to establish if juvenile stages of the predator would be consumed by their adults.

Later all stages of the predator including the eggs were introduced into new leaf discs. Observation was made and records taken on which stage of the prey was consumed most. Then males and female predators were introduced together without the other stages to establish also if they would consume one another.

2.14 Mortality

Experiments were set up to establish at what stage of development mortality occurred highest in N. idaeus under laboratory conditions.

Five N. idaeus eggs were introduced into each of ten leaf discs containing abundant prey. Observations were made at the same time daily to record mortality from the egg stage to the adult stage until the first eggs had been laid by all the females in the leaf discs. Eggs from this first generation were used to set up the second generation using the same procedure. Twelve generations were obtained and the experiment was terminated.

In order to determine at what stage of development mortality occurred highest from generation to generation the key factor analysis was employed, using the method of Varley, Gradwell and Hassell (1975), Pielou (1977) and Southwood (1984).

2.15 Life Table

Two Life Tables were constructed using the method of Birch (1948) as applied by Blommers (1976), Badii and McMurtry (1984) and Dinh et al. (1987). The intrinsic rate of increase, rm, was estimated using Lotka (1924) equation as applied by Laing (1968, 1969):

$$e^{-rmX} LxMx = 1$$

where 'e' is the base of the natural logarithm, 'X' is the age of the individuals in days, 'Lx' is the number of individuals alive at age 'X' as a proportion of 1 and 'Mx' is the number of female progeny produced per female in the age interval 'X'. The value of the negative exponent, "e-rmx" was obtained using the computer. The program was written and run by Dr. S. Nokoe of Ticks Research Programme, ICIPE

The 'rm' is got from the formula,

$dN/dt = rN$

or in the integrated form, $Nt = Noe^{rt}$ where No = Number of individuals at time Zero,

Nt = Number of individuals at time 't', and

r = Infinitesimal rate of increase (Birch, 1948).

In the present study, 'No' represents the number of

individuals at day '1' since 4 out of the individuals at day '0' died and did not contribute to the population under study, for Life Table 1. For Life Table 2 'No' is as earlier defined.

The finite rate of increase (λ = Lambda), that is, the number of times the population multiplies in a unit of time, is calculated from the formula : $\frac{Nt + 1}{Nt} = e^r$ = anti-loge r = λ. This represents a population which is increasing exponentially. So if there are Nt individuals at time t, then in one unit of time later, the ratio will give $Nt + 1 = e^r$ as explained above.

The net reproductive rate (Ro) is got from the formula: $Ro = \Sigma LxMx$
where LxMx are as defined earlier. This is the rate of multiplication in one generation and is the ratio of total female births in two successive generations (Birch, 1948).

The generation time (T) is got from the formula:
$T = \frac{\log_e Ro}{rm}$

where 'Ro' and 'rm' are as already defined. The mean generation time ($\bar{T}$) is therefore the relation between numbers and time in a population that is growing exponentially.

An approximate r_m, the capacity for increase (rc) is got from the formula: rc = logeRo/TC,

and Tc = $\sum$ XLxMx/ $\sum$ LxMx

where Tc is the cohort generation time, the mean age of the females in the cohort at the birth of the female offspring or the pivotal age where LxMx = 0.5 Ro (Southwood, 1984). $\bar{T}$ (the mean age of mothers of a cohort of newborn daughters) is given by the formula:

$$\bar{T} = \sum XLxMxe^{-r}xdx.$$

This, according to Pielou (1977) is a measure regarded by Leslie (1966) and Caughley (1967) as best both mathematically and biologically.

The values for the construction of the life table were got from the life history data. The intrinsic rate of increase was calculated from the age specific fecundity and survival rates under the defined environmental conditions in the present study. For the calculations of the generation time only T (Birch, 1948) and Tc (Pielou, 1977) were used.

3. RESULTS

3.1 Life Cycle and Development

The life history of N. idaeus is shown in Figure 12. The five developmental stages common to phytoseiids were completed by both the females and the males, namely Egg, Larvae, Protonymph, Deutonymph, Adult.

The eggs are laid singly on leaf veins, leaf ribs, grooves formed by the leaf ribs, leaf hairs and the web strands of the prey. The eggs are translucent when freshly laid as shown in Plate 8, Figure 1 and retain this colour until hatching. The larva has 3 pairs of walking legs as shown in Figure 2, Plate 9 and does not move much. It is translucent until it moults to the protonymph stage.

The protonymph and the subsequent stages have 4 pairs of walking legs (see Plates 10, 11, 12 and 13, and Figures 3, 4, 5 and 6). The protonymphs begin feeding on the prey eggs and larvae immediately on emergence. They are translucent like the larvae but soon change to the colour of the food they consume. They become bigger after feeding. The late protonymphs are, at times, difficult to distinguish from the deutonymphs.

The deutonymphs are larger than the protonymphs. The sexes can be distinguished at this stage due to size. The female deutonymphs are larger than the male deuto-

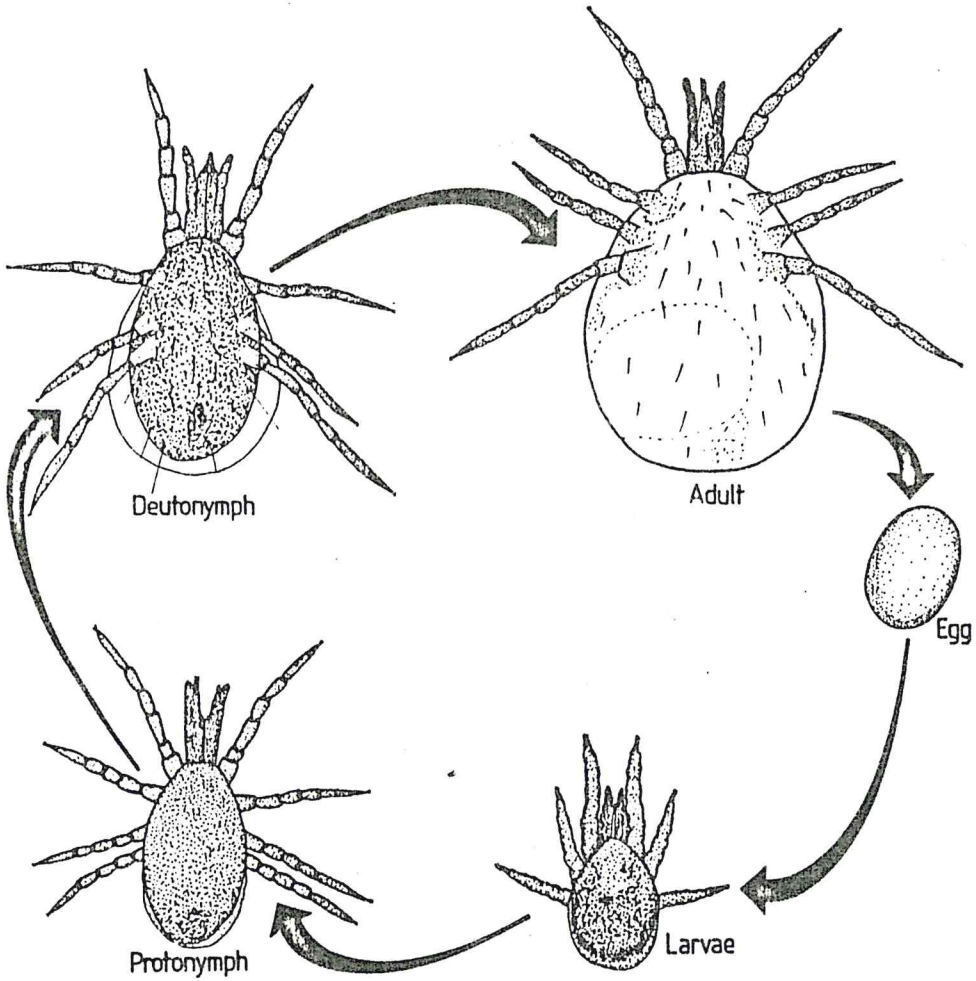

Fig. 12. Life cycle of N. idaeus on natural diet.

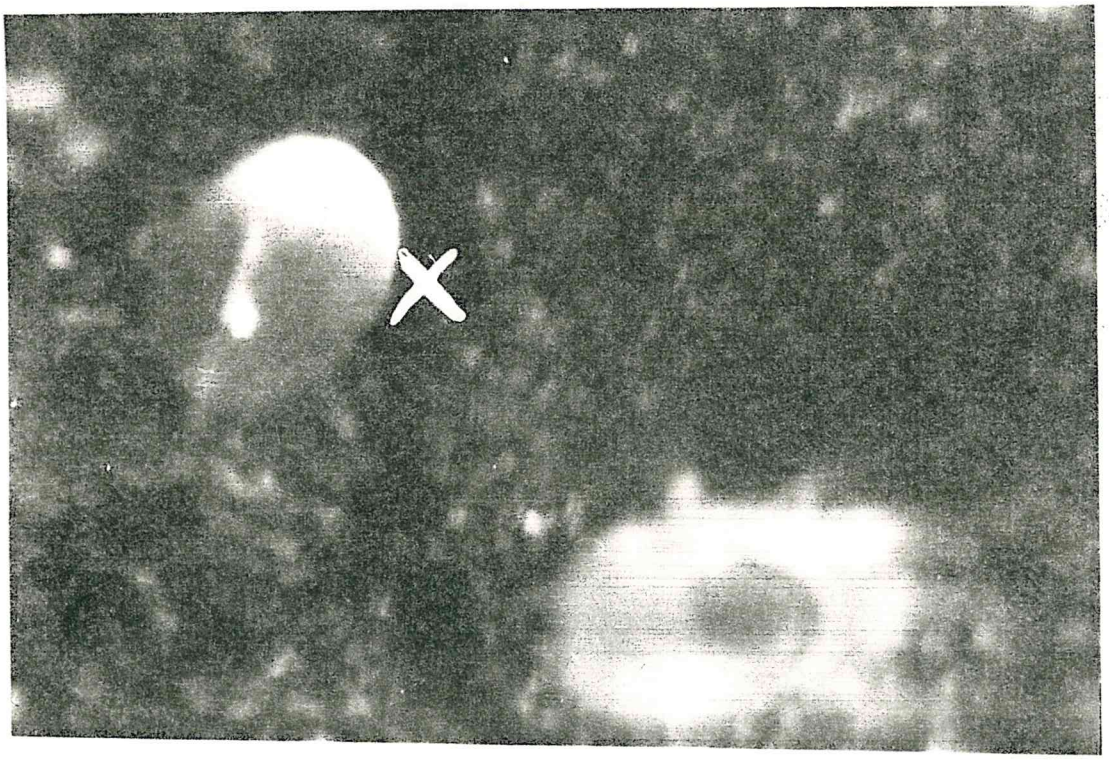

Plate 8. The egg stage of Neoseiulus idaeus when freshly laid. X = Fresh egg.

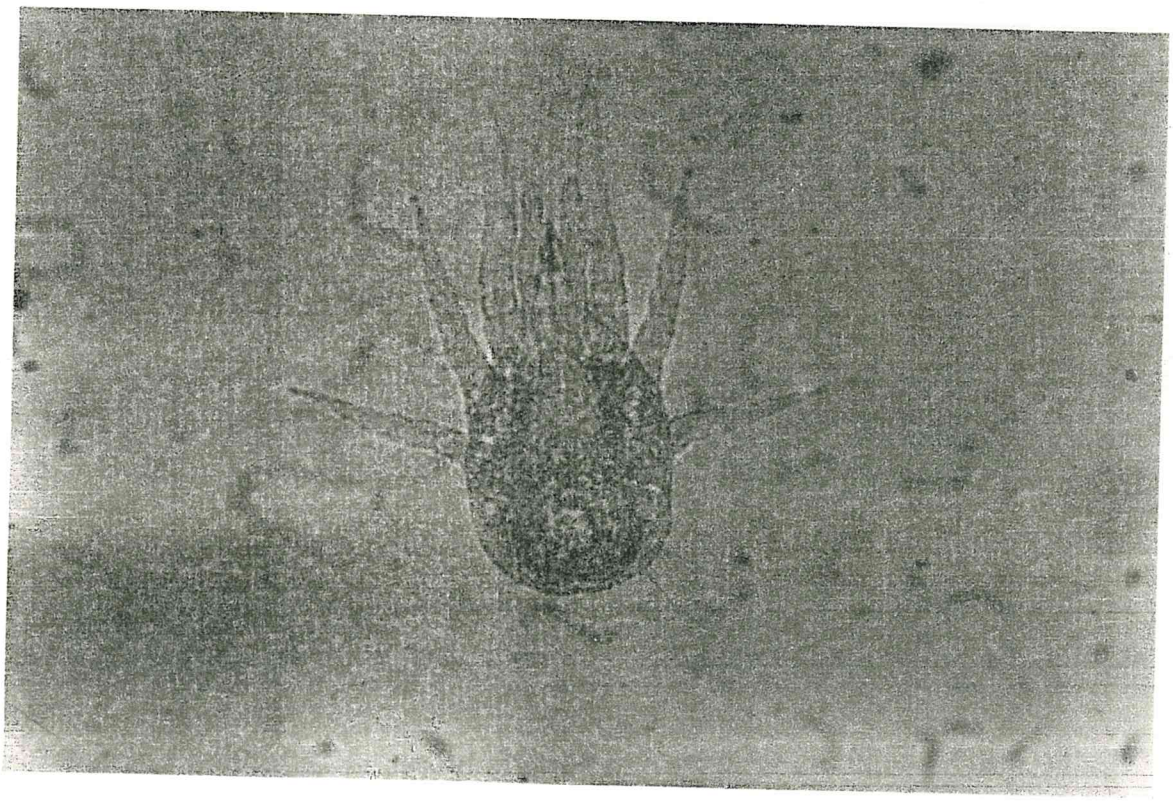

Plate 9. The larval stage of Neoseiulus idaeus

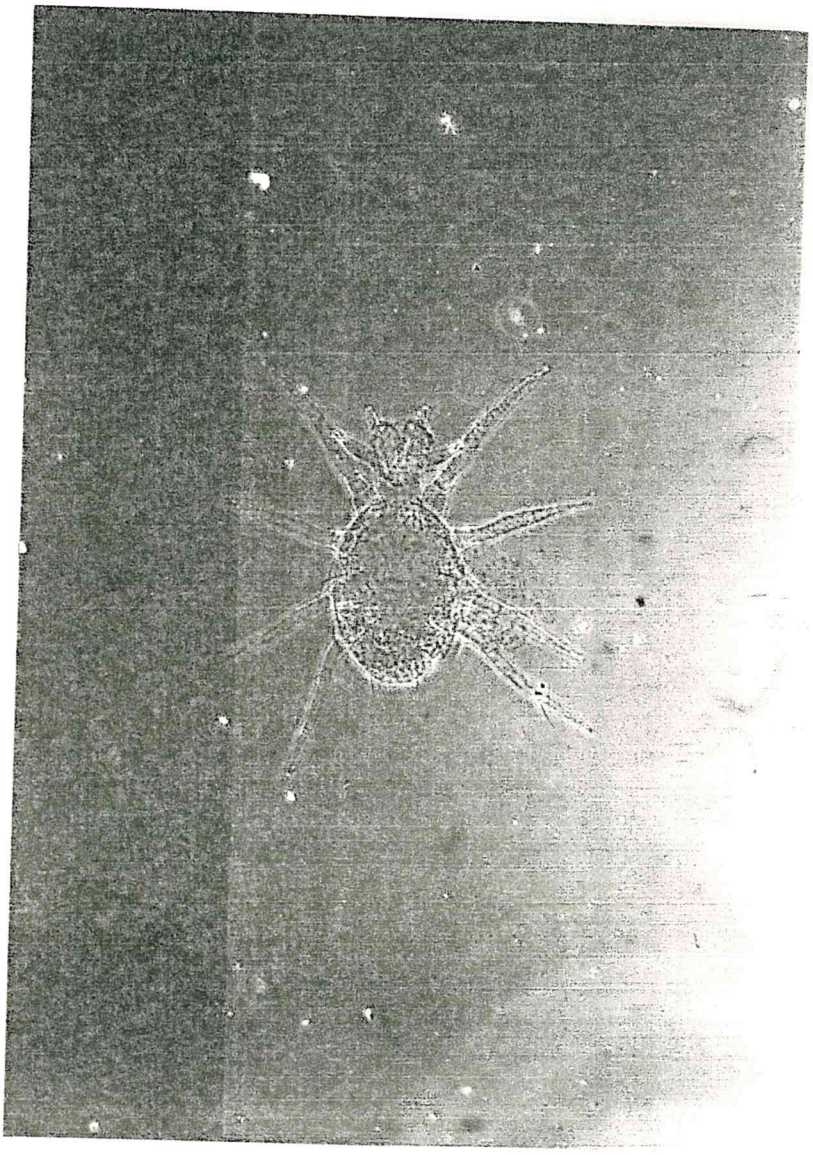

Plate 10. The protonymph stage of Neoseiulus idaeus

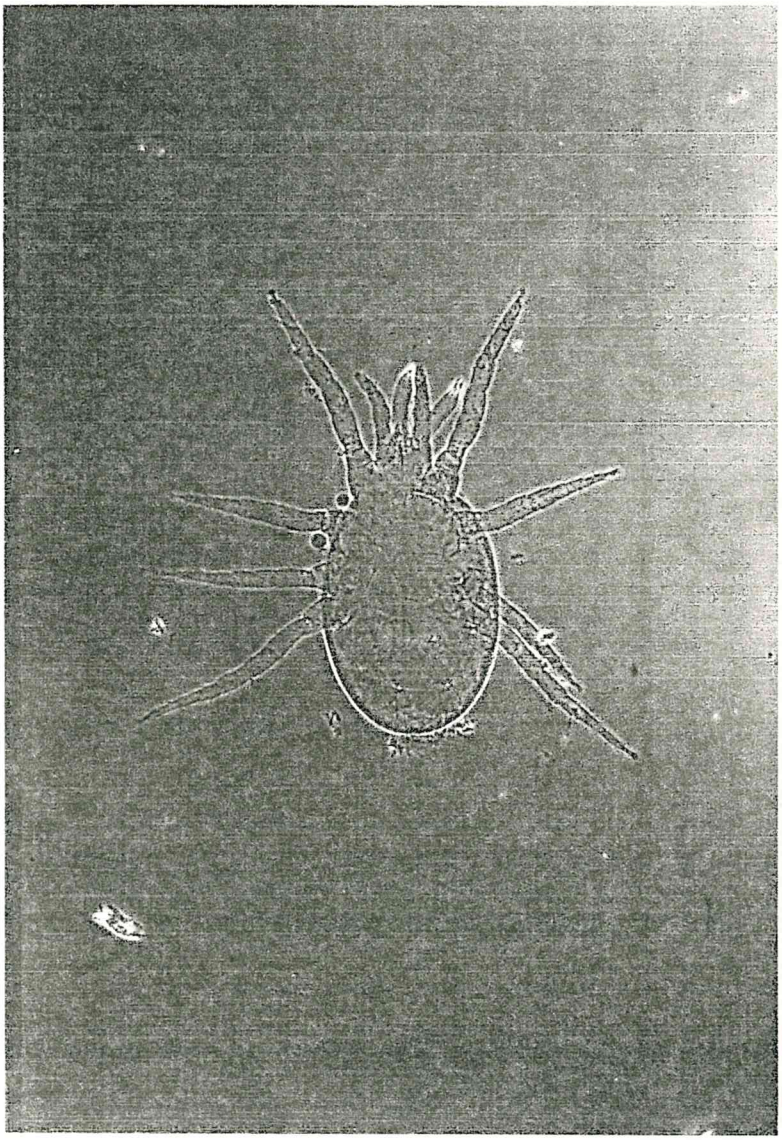

Plate 11. The deutonymph stage of Neoseiulus idaeus

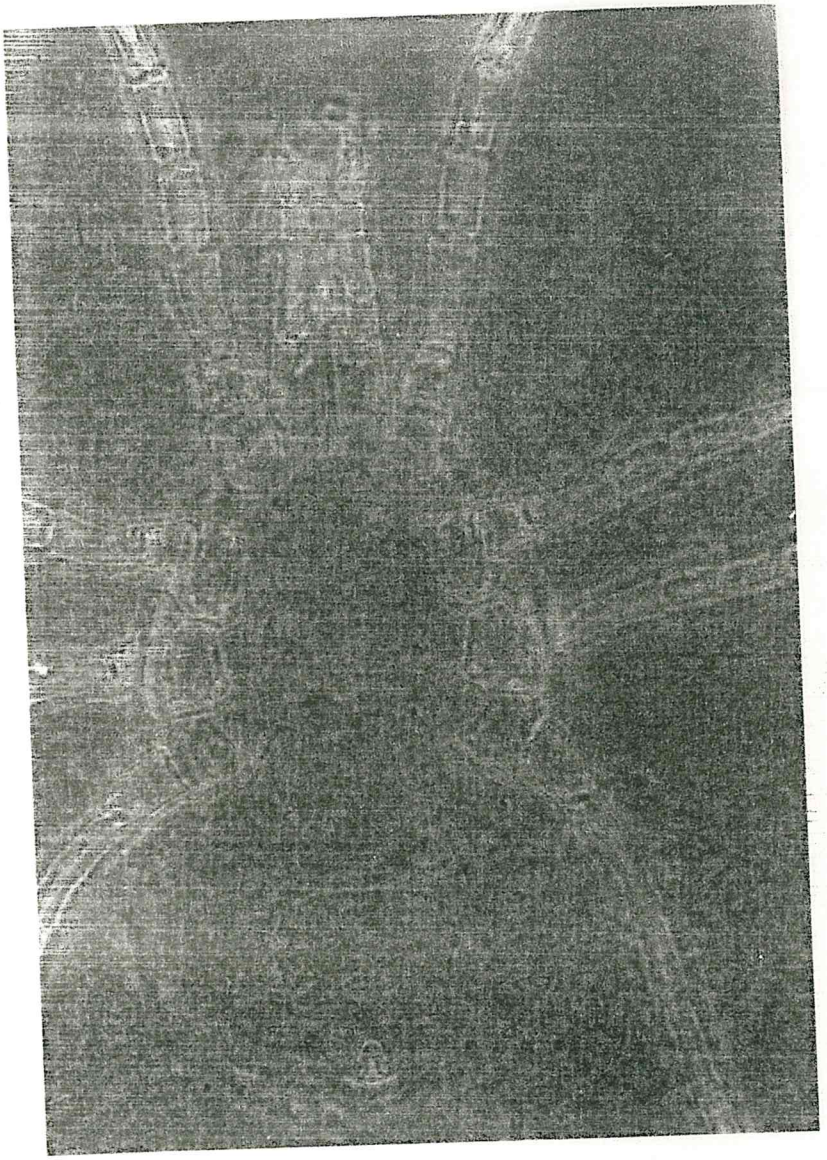

Plate 12. The adult stage of Female Neoseiulus idaeus

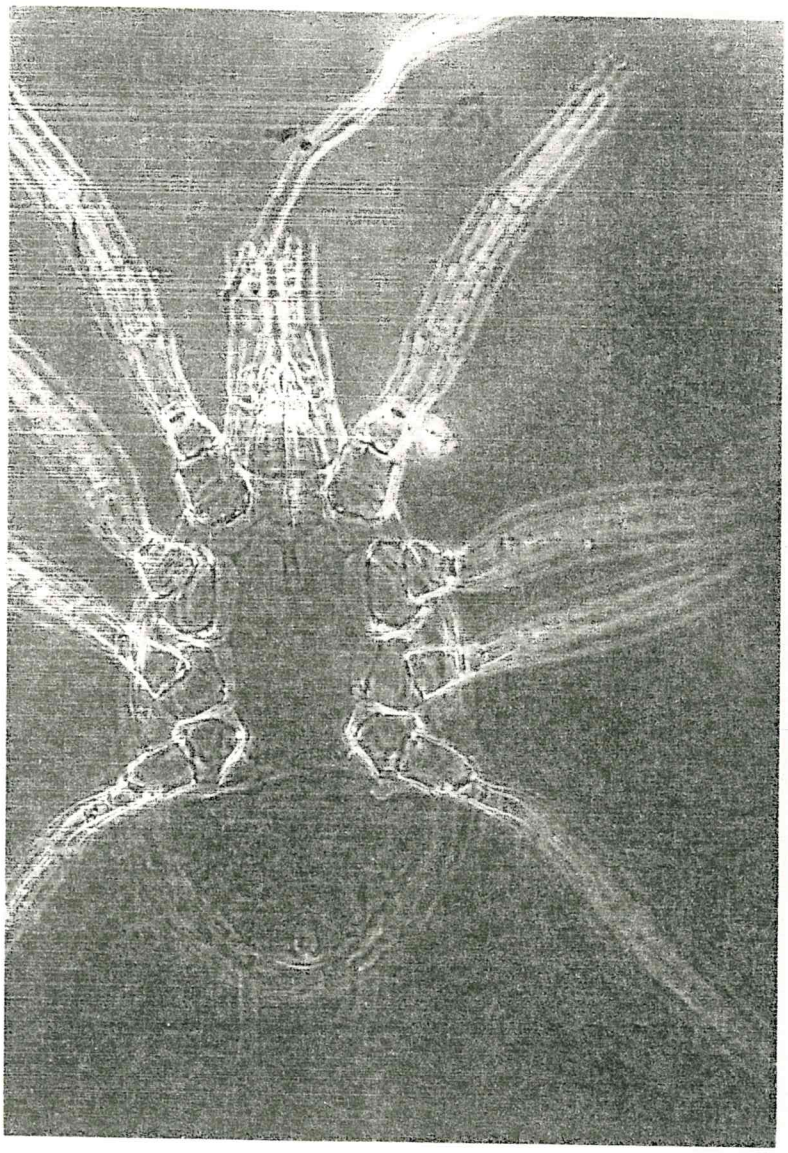

Plate 13. The adult stage of Male Neoseiulus **idaeus**

nymphs. They also assume the colour of the food they consume. Some specimens are milky in appearance while others are maroon in colour. The male deutonymphs moult to adults earlier and wait by the female deutonymphs to mate immediately the final moulting has taken place. So males develop a little faster than the females. The adult female and males are shown in Figures 5 and 6, Plates 12 and 13. The life stages were completed only on the natural diet as shown in Figure 13.

The adult males are bronze coloured while the adult females are light orange.

The results of six tests on the hatching time of the eggs on the three diet forms are presented in Table 3.1 (Appendix 1). In test 1 egg hatching took a longer period on the natural diet than on the two artificial diets, while there was no significant difference in the hatching time on the artificial diets. In test 2, the hatching time of the eggs on the three diets differred significantly at 5% level (L S D) whereas in test 3 there was no significant difference in the hatching time on the three diets. In tests 4, 5, and 6, the hatching time of the eggs on both the natural - and the artificial solid diets did not differ while both differred significantly from the artificial liquid diet. In all the six tests, hatching of the eggs was consistently faster on the artificial liquid diet than on the other two diets

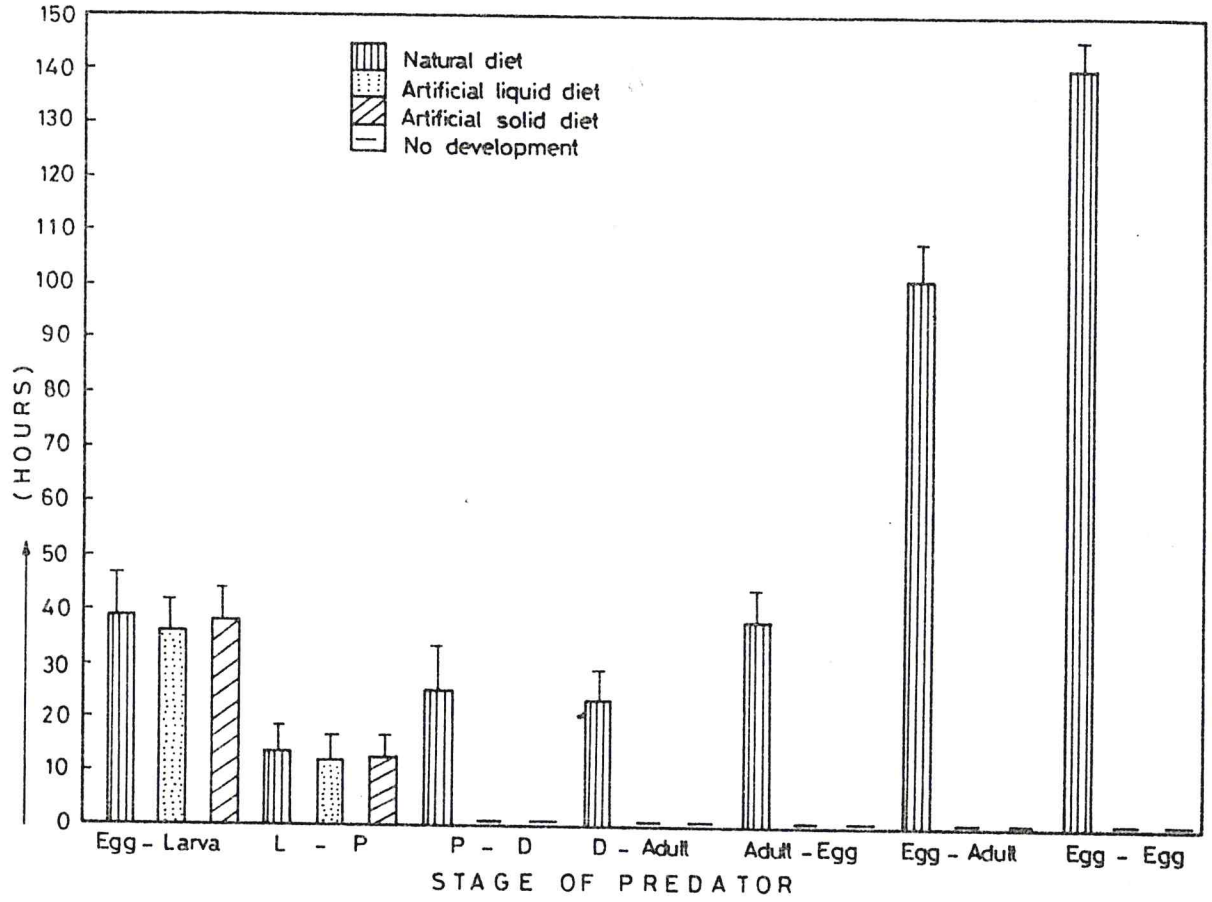

Fig. 13. Development of N. idaeus on natural-, artificial liquid-, and artificial solid diets.

Table 3.1 ANOVA For Egg - Hatching Time For Six Tests On Three Diet Types.

Source of Variation	df	MS Test 1	MS Test 2	MS Test 3	MS Test 4	MS Test 5	MS Test 6
Between	2	58.23	42.56	8.31	53.43	22.30	18.03
Within	27	2.59	2.15	3.86	3.14	3.38	3.99
Total	29						
LSD (5%)		1.48	1.35	NS	1.69	1.63	1.83
Means: A		39.7^{a}* $\pm$ 0.47	$40.4^{a} \pm 0.48$	$39.5^{a} \pm 0.40$	$39.05^{a} \pm 0.61$	$39.35^{a} \pm 0.38$	$39.4^{a} \pm 0.50$
B		$35.0^{b} \pm 0.61$	$36.3^{c} \pm 0.46$	$37.7^{a} \pm 0.87$	$34.80^{b} \pm 0.61$	$36.55^{b} \pm 0.85$	$36.9^{b} \pm 0.76$
C		$36.4^{b} \pm 0.42$	$38.75^{b} \pm 0.45$	$38.35^{a} \pm 0.49$	$38.50^{a} \pm 0.45$	$38.85^{a} \pm 0.38$	$39.0^{a} \pm 0.60$

*Means followed by the same letter are not significantly different at 5% level (LSD).

A = Natural Diet, B = Artificial Liquid Diet; and C = Artificial Solid Diet. NS = Not Significant.

while it took a longer time on the natural diet. A combined ANOVA on egg hatching time over the six experiments is presented in Table 3.2. There was an insignificant interaction between treatment (diets) and tests. There were no significant differences in the egg hatching time in the tests. Hatching time on the natural diet was however significantly different from the artificial liquid diet, but similar with solid diet.

The results of six tests for the larval development are presented in Table 3.3 (Appendix 2). In tests 1, 3, 4, 5, and 6, there was no significant difference in the development time of the larvae on the three diet forms. But in test 2, development time of the larvae on the natural diet differed significantly from the two artificial diets at 5% level, while there was no significant difference in the development time on the two artificial diets. A combined ANOVA on the development time of the larvae over the six experiments is presented in Table 3.4. Although the results on Test x diet interaction were highly significant indicating that comparison in diets should be done for each test separately one can conclude generally that there were no differences in the larval development times among the three diet situations as shown in Figure 14.

On the artificial liquid - and artificial solid diets, N. idaeus could not develop beyond the protonymph

Table 3.2 Combined ANOVA On Egg-Hatching Time Over The Six Experiments (Repetitions).

Source of Variation	df	SS	MS	F-ratio
Between Tests	5	59.4944	11.90	1.97
Between Treatments	2	345.4361	172.72	28.55**
Test x Treatment (Experimental Error)	10	60.5056	6.05	1.90
Sampling Error	162	516	3.185	
Total	179			

Coefficient of variation = 6.05%

** Significant at 1% level

LSD = 3.16

Diets	A	C	B
	39.57^{a*}	38.31^{ab}	36.21^{b}

*Meansfollowed by the same letter are not significantly different at 5% level (LSD).

Table 3.3. ANOVA For Larval Development For Six Tests

Source of Variation	df	MS Test 1	MS Test 2	MS Test 3	MS Test 4	MS Test 5	MS Test 6
Between	2	8.41	8.76	4.58	4.43	2.06	4.98
Within	27	2.53	1.29	2.13	2.22	1.36	2.28
Total	29						
LSD		NS	1.04	NS	NS	NS	NS
Means: A		$12.80^{a} \pm 0.44$	$13.25^{a*} \pm 0.43$	$13.80^{a} \pm 0.47$	$12.65^{a} \pm 0.52$	$13.45^{a} \pm 0.39$	$11.60^{a} \pm 0.71$
B		$11.05^{a} \pm 0.69$	$11.50^{b} \pm 0.37$	$12.45^{a} \pm 0.58$	$12.75^{a} \pm 0.60$	$12.60^{a} \pm 0.37$	$13.00^{a} \pm 0.32$
C		$12.40^{a} \pm 0.29$	$11.80^{b} \pm 0.25$	$13.05^{a} \pm 0.29$	$11.55^{a} \pm 0.19$	$12.75^{a} \pm 0.34$	$12.45^{a} \pm 0.27$

*Significant at 5% level.

Means followed by the same letter are not significantly different at 5% level (LSD).

A = Natural Diet; B = Artificial Liquid Diet; and C = Artificial Solid Diet.

NS = Not Significant (ANOVA).

Table 3.4 Combined ANOVA On Development Time of Larvae Over The Six Experiments.

Source of Variation	df	SS	MS	F-ratio
Between Tests	5	26.3278	5.27	1.06 ns
Between Treatments	2	17.0000	8.50	1.71 ns
Test x Treatment (Experimental Error)	10	49.6722	4.97	2.52*
Sampling Error	162	319	1.97	

Coefficient of variation = 11.91%

LSD = 2.04

ns = not significant.

* = significant at the 5% level.

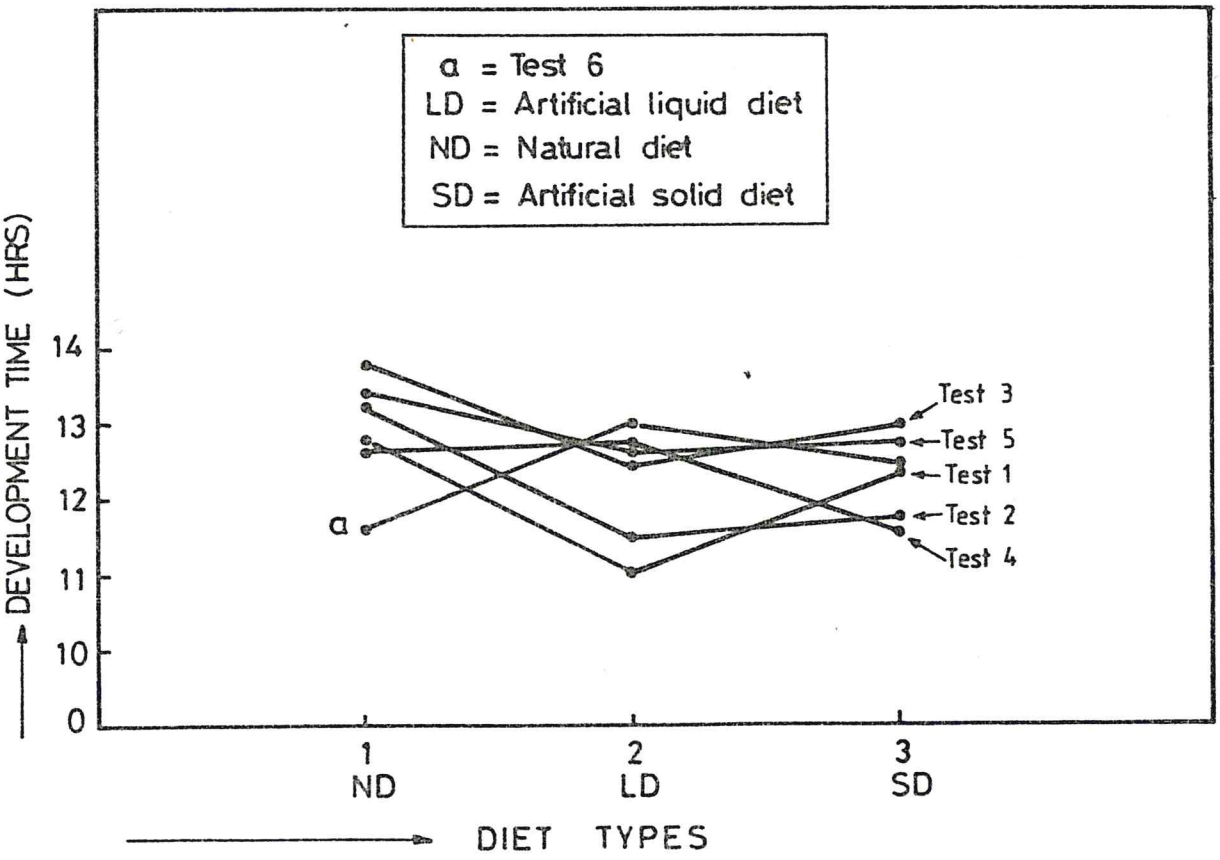

Fig. 14. A graph showing test x treatment interaction on larval development over six tests.

stage as shown in Table 3.5 (Appendix 3). After two days in the protonymph stage, the predators died without further development. But on the natural diet, development continued up to the deutonymph stage and the adult stage (Appendix 4). The development from the egg stage to the adult stage took 101.98 hours (4.23 days) while egg to egg stage (developmental time) took 140.01 hours (5.83 days). The preoviposition period on the natural diet was 38.02±0.55 hours (i.e. adult to egg) (Appendix 5). Out of twenty predators observed very closely, five had delayed mating with the average time of 41.4±2.61 hours while those that mated immediately on emergence had an average preoviposition period of 36.9±0.96 hours. When the total records were put together, the average preoviposition period was 38.03±0.55 (SE) hours. Zero time was recorded on the artificial liquid - and artificial solid diets for these times.

3.2 Measurements of the various Life Stages

The results of this are presented in Table 3.6. The length of the eggs did not vary. The average length of the eggs was 0.18 mm, while the width varied a little bit between 0.15- and 0.14 mm. The size of the larva did not vary much since they did not feed. However, those that would develop into females were a bit larger than those that would develop into males (Pers. obs.).

The protonymphs were almost the same size as the larvae immediately on emergence, but became markedly

Table 3.5. Egg-to-Egg Development of N. idaeus On Natural-, Artificial Liquid-, and Artificial Solid Diets.

Predator Stage	Development Time (hrs) (Mean ± SE). Natural Diet	Art. Liquid Diet	Art. Solid Diet.
Egg - Larva	39.57[a]* ± 0.20	36.21[b] ± 0.31	38.31[ab] ± 0.22
Larva - Protonymph	12.93[a] ± 0.22	12.23[a] ± 0.11	12.33[a] ± 0.13
Protonymph - Deutonymph	25.08 ± 0.27	0.00	0.00
Deutonymph - Adult Stage	24.4 ± 0.21	0.00	0.00
Adult - Egg	38.03 ± 0.55	0.00	0.00
Egg - Adult	101.98	0.00	0.00
Egg - Egg.	140.01	0.00	0.00

*Means followed by the same letter are not significantly different at 5% level (LSD)

Table 3.6. Measurements of the various life stages of N. idaeus

STAGE	LENGTH	WIDTH	MEAN ± SE
Egg	0.18 ± 0.00	0.14 ± 0.00	mm
Larvae	230.85 ± 2.10	163.90 ± 3.81	µm
Protonymph	260.08 ± 5.38	174.33 ± 4.74	µm
Deutonymph	356.12 ± 16.14	232.14 ± 9.68	µm
Adult female	469.68 ± 12.59	305.91 ± 12.42	µm
Adult male	314.92 ± 3.66	208.70 ± 5.05	µm

bigger after feeding. Protonymphs of 16-20 hours old were almost the same size as deutonymphs in the early stages of development.

The female deutonymphs were larger in size than most of the adult males (see Figures 4 and 6). The largest female deutonymph was 530.45 µm in length and 350.2 µm in width, while the largest adult male was 334.75 µm in length and 242.05 µm in width. The adult females maintained consistently a uniform size, the largest being 561.35 µm in length and 391.4 µm in width. The smallest adult female (non-gravid) was 309 µm in length and 205 µm in width. The females are much larger than the males and the other stages because of their gravid nature (see Appendix 6 and Plate 14).

3.3 Fecundity and Sex Ratio

The results on fecundity and sex ratio of N. idaeus of the first test are presented in Table 3.7. Each of the fourteen mites was regarded as a replicate.

The highest number of eggs laid by a female was 47 in an oviposition period of 19 days, while the lowest was 5 eggs in 4 days. The longest lived ovipositing female was 33 days with the shortest-lived as 4 days. Many of the mites died during the egg-laying period and would not have laid their full complement of eggs, hence fecundity was low (20.36±3.18).

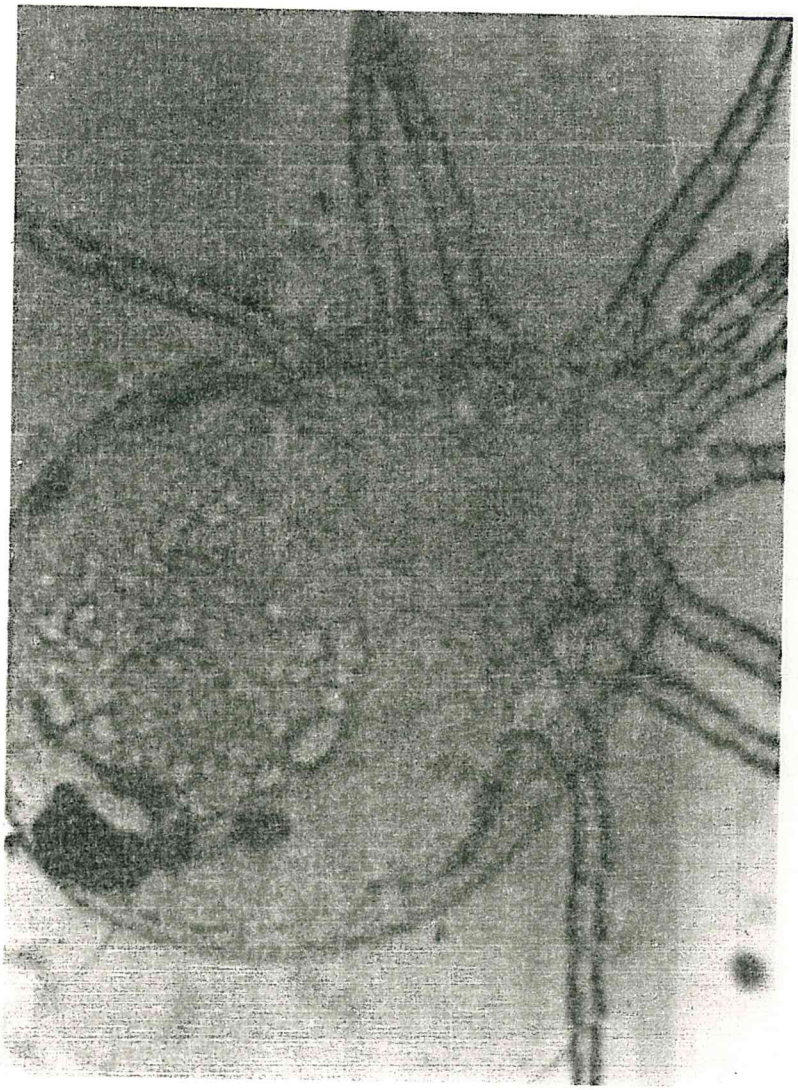

Plate 14. A gravid female of Neoseiulus idaeus

Table 3.7. Fecundity and Sex Ratio of *N. idaeus* on Natural Diet.

Test 1 (Mean±SE)

Rep	No. Eggs Laid	No. Larvae Hatched	No. Reaching Adult Stage	Females	Males	Ratio	Rate of Oviposition	Longevity of Ovip. Fem.	No. of days laid
1	12	9	9	7	2	3.5:1	2.4	7	5
2	27	23	23	21	2	10.5:1	2.25	14	12
3	47	36	36	28	8	3.5:1	2.47	33	19
4	12	9	8	7	1	7:1	2.4	6	5
5	32	26	26	22	4	5.5:1	2.91	14	11
6	22	21	18	15	3	5:1	2.75	9	8
7	6	6	5	4	1	4:1	1.5	6	4
8	12	11	11	8	3	2.67:1	2.4	6	5
9	29	24	23	18	5	3.6:1	2.23	16	13
10	15	13	11	9	2	4.5:1	3.0	7	5
11	5	2	2	1	1	1:1	1.25	5	4
12	32	20	18	16	2	8:1	2.0	26	16
13	21	14	14	9	5	1.8:1	2.63	9	8
14.	13	6	6	5	1	5:1	1.86	21	7
Mean	20.36						2.29	12.79	8.71
SE	3.18						0.13	2.29	1.28

% Eggs hatched = 76.06 4.65
% Reaching adult stage from egg = 71.66 4.03
% Females in the adult population = 78.69 2.87
Mean Sex Ratio (F:M) = 4.25:1.

The average rate of oviposition was 2.29±0.13 eggs per female per day. At the early stage of oviposition the general rate was between 3 and 4 eggs per female per day, particularly when prey supply was ample, but this rate declined during periods of prey scarcity and/or towards the tail end of oviposition. The observed sex ratio for the population was 4.25 females to 1 male (4.25:1).

The results of the second test are presented in Table 3.8. Each of the nine mites was also regarded as a replicate.

The highest number of eggs laid by a female was 38 ovipositing for only 17 days. The lowest was 2 and the female died after one day. Almost all the mites died within the egg laying period and would also not have laid their full complement of eggs, hence the low fecundity (14.56±4.18). The average rate of oviposition was 2.10±0.16 eggs per female per day. The observed sex ratio was 2.41 females to 1 male (2.41:1).

The results of the third test are presented in Table 3.9. The experiment was terminated after 11 days while the mites were still laying. The highest number of eggs recorded was 35 while the lowest was 17. Since the mites were still laying eggs this did not represent their full complement of eggs. The average fecundity within this period was 29.8±3.38 eggs per female. The average

Table 3.8. Fecundity and Sex Ratio on Natural Diet

Test 2 (Mean±SE)

Rep	No. Eggs Laid	No. Larvae Hatched	No. Reaching Adult Stage	Females	Males	Ratio	Rate of Oviposition	Longevity of Ovip. Fem.	No. of days laid
1	15	11	11	7	4	1.75:1	2.14	11	7
2	2	1	1	0	1	0:1	2.0	3	1
3	5	5	5	4	1	4:1	1.67	3	3
4	7	7	7	2	5	0.4:1	1.4	26	5
5	32	28	28	22	6	3.67:1	2.91	11	11
6	15	12	12	7	5	1.4:1	1.67	13	9
7	5	4	4	3	1	3:1	2.5	3	2
8	38	31	31	24	7	3.43:1	2.24	21	17
9	12	10	10	8	2	4:1	2.4	11	5
Mean	14.56						2.10	11.33	6.67
SE	4.18						0.16	2.69	1.68

% Eggs hatched = 81.75 ± 4.98
% Reaching adult stage from egg = 81.75 ± 4.98
% Females in the adult population = 67.69 ± 6.27
Mean Sex Ratio (F:M) = 2.41:1

Table 3.9. Fecundity and Sex Ratio on Natural Diet

Test 3 (Mean±SE)

Rep/	No. Eggs Laid	No. Larvae Hatched	No. Reaching Adult Stage	Females	Males	Ratio	Rate of Ovip	Longevity of Ovip. Fem.	No. of days Laid
1	35	29	21	15	6	2.5:1	3.18	11	11
2	35	20	15	11	4	2.75:1	3.18	11	11
3	29	15	10	9	1	9:1	2.64	11	11
4	17	15	9	6	3	2:1	1.55	11	11
5	33	20	18	12	6	2:1	3.0	11	11
Mean	29.8						2.71	11.0	11.0
SE	3.38						0.31	0.00	0.00

% Eggs hatched = 68.11 ± 7.31
% Reaching adult stage from egg = 48.97 ± 4.56
% Females in the adult population = 73.62 ± 4.30
Mean Sex Ratio (F:M) = 2.65:1

rate of oviposition was 2.71±0.31 eggs per female per day. The observed sex ratio was 2.65 females to 1 male (2.65:1). Hatching was poor as not many of the eggs hatched, and among those that hatched only few reached adult stage. In all the three experiments there were generally more females than males in the population.

The result of Heterogeneity Chi-Square analysis for test 1 is presented in Table 3.10. For tests 2 and 3 the results are presented in Tables 3.11 and 3.12 respectively. Chi-Squared tests performed individually on each replicate per test for a hypothesized sex ratio of 5 females to 1 male (5:1) was not significant for test 1 and 3 but the hypothesis was rejected in test 2 as shown in Table 3.11. A combined Heterogeneity Chi-Square analysis for the three tests based on the ratio 5:1 (see Table 3.13) indicated samples used for the tests particularly those from test 2 could have come from a different population.

Chi-Squared tests based on the ratios 4 females to 1 male and 3 females to 1 male were also performed individually on each replicate per test, and for the combined tests. The results of the tests based on the ratio 4:1 are presented in Table 3.14. Individual Chi-Squared tests based on this ratio were not significant for tests 1 and 3, but significant (Ho rejected) for two replicates of test 2. Similarly the combined Chi-Squared test based on the ratio 4:1 was confirmed in

Table 3.10 Heterogeneity Chi-Square Analysis For A Hypothesized Sex Ratio of 5 females to 1 male (5:1)

Test 1

Rep.	No. of Adults	Females	Males	Ratio	Chi-Square	DF
1	9	7	2	3.5:1	0.2 ns	1
2	23	21	2	10.5:1	1.051 ns	1
3	36	28	8	3.5:1	0.8 ns	1
4	8	7	1	7:1	0.1 ns	1
5	26	22	4	5.5:1	0.031 ns	1
6	18	15	3	5:1	0.00	1
7	5	4	1	4:1	0.04 ns	1
8	11	8	3	2.67:1	0.982 ns	1
9	23	18	5	3.6:1	0.426 ns	1
10	11	9	2	4.5:1	0.018 ns	1
11	2	1	1	1:1	1.603 ns	1
12	18	16	2	8:1	0.4 ns	1
13	14	9	5	1.8:1	3.659 ns	1
14	6	5	1	5:1	0.00	1
Total Chi-Square					9.22	14
Chi-Square of Totals					0.857	1
Heterogeneity Chi-Square					8.363 ns	13

ns = not significant

Table 3.11 Heterogeneity Chi-Square Analysis (Ratio 5:1)

Test 2

Rep.	No. of Adults	Females	Males	Ratio	Chi-Square	DF
1	11	7	4	1.75:1	3.074 ns	1
2	1	0	1	0:1	4.988*	1
3	5	4	1	4:1	0.040 ns	1
4	7	2	5	0.4:1	15.108*	1
5	28	22	6	3.67:1	0.457 ns	1
6	12	7	5	1.4:1	5.400*	1
7	4	3	1	3:1	0.199 ns	1
8	31	24	7	3.43:1	0.780 ns	1
9	10	8	2	4:1	0.080 ns	1
Total Chi-Square					30.126*	9
Chi-Square of Totals					12.64*	1
Heterogeneity Chi-Square					17.486*	8

*Significant at 5% level.

Table 3.12 Heterogeneity Chi-Square Analysis (Ratio 5:1)

Test 3

Rep.	No. of Adults	Females	Males	Ratio	Chi-Square	DF
1	21	15	6	2.5:1	2.143 ns	1
2	15	11	4	2.75:1	1.08 ns	1
3	10	9	1	9:1	0.32 ns	1
4	9	6	3	2:1	1.8 ns	1
5	18	12	6	2:1	3.6 ns	1

Total Chi-Square	8.943	5
Chi-Square of Totals	6.052	1
Heterogeneity Chi-Square	2.891 ns	4

Table 3.13 Heterogeneity Chi-Square Analysis for Combined Tests (Ratio 5:1)

Tests	Female	Male	Total	Chi-Square	DF
1	170	40	210	0.857 ns	1
2	77	32	109	12.64 ***	1
3	53	20	73	6.052*	1
	(300)	(92)	(392)		
Total Chi-Square				19.549	3
Chi-Square of Totals				13.062	1
Heterogeneity Chi-Square				6.487*	2

* Significant at P = 0.05

*** Significant at P = 0.001

Table 3.14 Heterogeneity Chi-Square Analysis For A Hypothesized Ratio of 4 females to 1 male (4:1)

Rep	Chi-Square Test 1	DF	Chi-Square Test 2	DF	Chi-Square Test 3	DF
1	0.028	1	1.841	1	0.964	1
2	1.837	1	4.0*	1	0.416	1
3	0.111	1	0.00	1	0.625	1
4	0.281	1	11.571*	1	1.00	1
5	0.346	1	0.036	1	1.00	1
6	0.125	1	3.521	1		
7	0.00	1	0.063	1	Total Chi-square 5.005	5
8	0.364	1	0.129	1	Chi-square Total 2.496	1
9	0.044	1	0.00	1	Het. Chi-Square 2.509 ns	4
10	0.023	1				
11	1.125	1	Total Chi-Square 21.161	9		
12	0.889	1	Chi-Square of Totals 5.965	1		
13	2.161	1	Het. Chi-Square 15.198 ns	8		
14	0.041	1				
To.Chi-Sq.	7.375	14				
Chi-Sq. To.	3.000	1				
Het. Chi-Sq.	4.375ns	13				

* Significant at P. = 0.05

To = Total

Het.Chi-Sq. = Heterogeneity Chi-Square

ns = Not significant

tests 1 and 3, but rejected in test 2 as shown in Table 3.15. However, the result of the Heterogeneity Chi-Square analysis for each of the tests and for the combined tests based on this ratio was not significant, thus confirming that the samples could have come from the same population.

The results of Chi-Squqred tests based on the ratio 3 females to 1 male are presented in Table 3.16. Only one replicate in test 2 showed high significance (P=0.01). This hypothesis was confirmed by combined data for tests 2 and 3, but rejected by data from test 1 as shown in Table 3.17. The results of Heterogeneity Chi-Squared test on the combined tests based on this ratio was not significant thus, further confirming that the samples could have come from the same population. These results show that the sex ratio of N. idaeus would be between 3- and 4 females to 1 male (3.5:1).

3.4 Mating Behaviour and Parthenogenesis

Mating of N. idaeus was a prolonged process lasting for about two and half hours. The males approached the females from the rear. The female tilted its abdomen and the male crawled underneath. Both mated venter to venter. In this position the female could run carrying the male. Many a time the males waited by the female deutonymphs about to moult. As soon as the posterior end of the female was withdrawn from the exuvium, the

Table 3.15 Heterogeneity Chi-Square Analysis For Combined Tests (Ratio 4:1)

Tests	Chi-Square	DF
1	0.119	1
2	5.965*	1
3	2.496	1
Total Chi-Square	8.58	3
Chi-Square of Totals	2.949	1
Heterogeneity Chi-Square	5.631 ns	2

* Significant at 5% level.

Table 3.16 Heterogeneity Chi-Square Analysis For A Hypothesized Ratio of 3 females to 1 male (3:1)

Rep	Chi-Square Test 1	DF	Chi-Square Test 2		DF	Chi-Square Test 3		DF
1	0.037	1		0.757	1		0.143	1
2	3.261	1		3.000	1		0.023	1
3	0.148	1		0.067	1		1.200	1
4	0.643	1		8.048**	1		0.333	1
5	1.283	1		0.191	1		0.667	1
6	0.667	1		1.777	1			
7	0.067	1		0.00	1	Total Chi-square	2.366	5
8	0.031	1		0.097	1	Chi-square Total	0.224	1
9	0.131	1		0.133	1	Het. Chi-Square	2.142 ns	4
10	0.273	1						
11	0.667	1	Total Chi-Square	14.07	9			
12	1.852	1	Chi-Square of Totals	1.104	1			
13	0.857	1	Het. Chi-Square	12.966 ns	8			
14	1.223	1						
To.Chi-Sq.	11.14	14						
Chi-Sq. To.	3.968	1						
Het. Chi-Sq.	7.172 ns	13						

**Significant at P = 0.01

To = Total

Het.Chi-Sq. = Heterogeneity Chi-Square

Table 3.17 Heterogeneity Chi-Square Analysis For Combined Tests (Ratio 3:1)

Tests	Chi-Square	DF
1	3.968*	1
2	1.104	1
3	0.224	1
Total Chi-Square	5.296	3
Chi-Square of Total	0.489	1
Heterogeneity Chi-Square	4.807 ns	2

* Significant at P. 0.05.

male crawled underneath and mated with her immediately. In some cases they assisted to remove the deutonymphal exuvia. The male also mated the female by climbing on her dorsum first and later crawled underneath for the mating process.

The results on parthenogenesis showed that the ten females without males did not oviposit while those which had males introduced to them oviposited. Five of the ten females that did not oviposit, later on oviposited when males were introduced unto them. Mating was, therefore, essential for oviposition.

During the course of the experiment it was observed that females which mated only once ceased oviposition prematurely, and when they were once more exposed to males, they resumed oviposition. This showed that constant mating was required for continued oviposition and for the female to lay her full complement of eggs.

3.5 Longevity

The results of longevity of N. idaeus on five - food situations are presented in Table 3.18, Figure 15. The life span of the mites on the natural diet differed significantly at 5% level from the other diet situations, while no significant differences were observed among the other diet situations(Appendix 7). Results were confirmed by the Duncan's Multiple Range Test(DMRT) and Single

Table 3.18 ANOVA On Longevity of N. idaeus on Five - Food Situations.

Source of Variation	df	SS	MS	F-ratio	F-tab
Between	4	1030.048	257.512	14.03**	2.61
Within	40	734.04	18.351		
Total	44	1764.088			

**Significant at the 1% level

Coefficient of variation = 84.11%

SE = 2.06

Means:

D	E	B	C	A
1.28^{b}	2.32^{b}	2.60^{b}	4.00^{b}	13.88^{a*}

*Means followed by the same letter are not significantly different at 5% level (DMRT).

A = Natural Diet; B = Artificial Liquid Diet; C = Artificial Solid Diet; D = No - food situation; and E = Modified Artificial Liquid Diet.

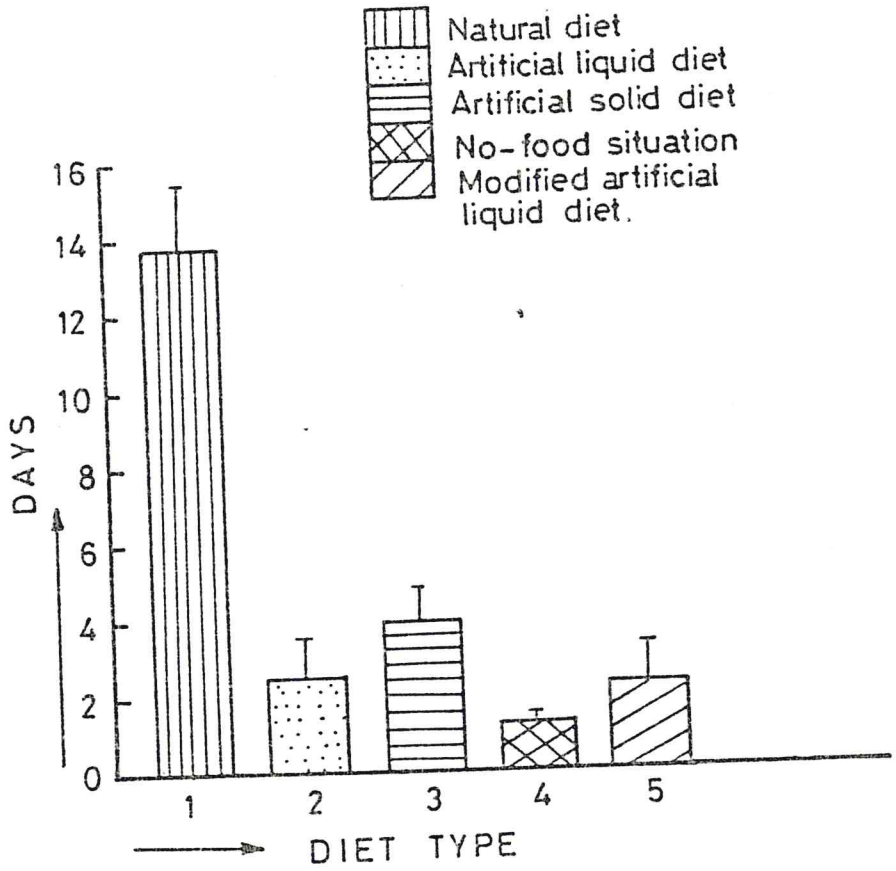

Fig. 15. Histogram showing longevity of N. idaeus on natural-, artificial liquid-, artificial solid-, a no-food situation, and a modified artificial liquid diet.

DF Orthogonal Contrasts. The DMRT was used to separate the means.

When the life span of the adult males and females was compared with the mixed sex (i.e. male and female together) on a no-food situation the males lived significantly longer (P = 0.05) than the females or the mixed sex. Results are presented in Table 3.19, Figure 16 (Appendix 8).

The longevity of the mites was also compared on the artificial liquid - and the artificial solid diets when confined with Vaseline, Talcum powder or without confinement (Appendix 9). The results are presented in Table 3.20, Figure 17. Though there was no significant difference in the longevity of the mites with or without confinement on the two artificial diets, the significant interaction between confinement and diet showed that at least in some cases differences existed when the mites were confined with either vaseline, talcum powder or without confinement as shown in Figure 18. Longevity was higher on the solid diet when the mites were confined with vaseline than with powder, while the liquid diet did slightly better without confinement than with powder or vaseline for confinement. But statistical analysis showed that these differences were not significant at 5% level.

The results for days to percentage extinction of the mites on the different food situations are presented

Table 3.19 ANOVA on Longevity of Male, Female and Mixed Sex of *N. idaeus* on a No - Food Situation.

Source of Variation	df	SS	MS	F-ratio	F-tab
Between	2	2.356	1.178	11.34*	3.35
Within	27	2.804	0.104		
Total	29	5.16			

Coefficient of variation = 20.23%

SE = 0.10

Means:	C	A	B
	1.28^{b}	1.54^{b}	1.96^{a*}

Means followed by the same letter are not significantly different at 5% level (DMRT).

A = Female; B = Male; C = Mixed Sex

* Significant at 5% level

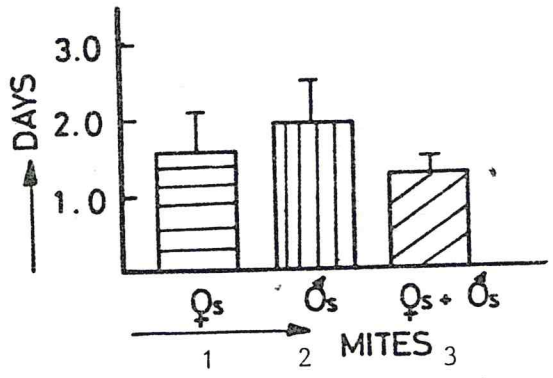

Fig. 16. Histogram showing longevity of adult females, males and a mixed sex of N. idaeus on a no-food situation.

1 =Females; 2 = Males; 3 = Mixed sex (F+M)

Table 3.20 ANOVA on Length of Life Span of N. idaeus on Artificial Liquid - and Artificial Solid Diets When Confined with Vaseline, Talcum Powder and with No - Confinement.

Source of Variation	df	SS	MS	F-ratio
Confinement	2	10.62	5.31	1.31 ns
Diet	1	4.37	4.37	1.08 ns
Confinement x Diet	2	8.08	4.04	5.05**
(Experimental Error)				
Sampling Error	54	43.2	0.80	

ns = not significant

** = significant at 0.01

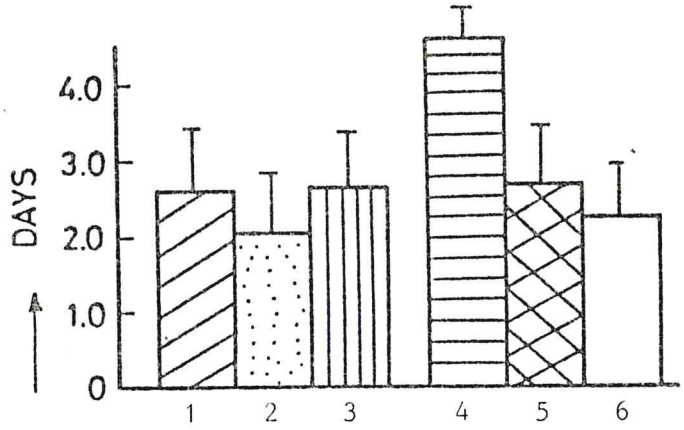

Fig. 17. Histogram showing longevity of N. idaeus on artificial liquid - and artificial solid diets when confined with vaseline, talcum powder or without confinement.

1 = Artificial liquid diet with vaseline for confinement; 2 = artificial liquid diet with talcum powder for confinement; 3 = artificial liquid diet without confinement; 4 = artificial solid diet with vaseline for confinement; 5 = artificial solid diet with talcum powder for confinement; 6 = artificial solid diet without confinement.

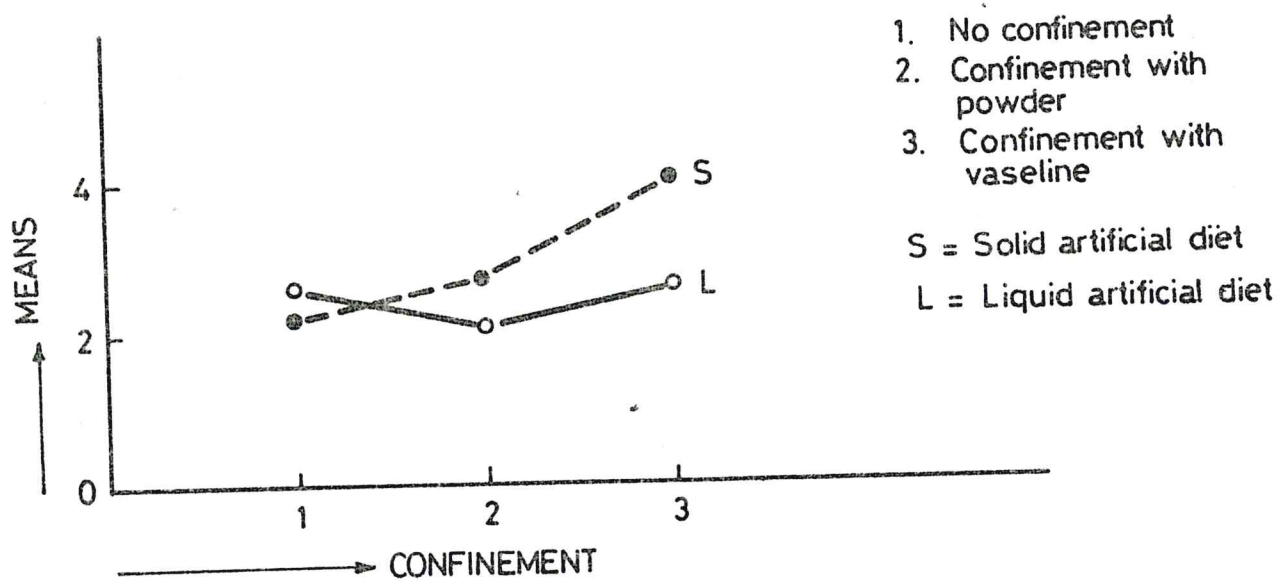

Fig. 18. A graph of interaction between diet and confinement showing differences in longevity.

in Table 3.21, Figures 19-23. The mites took a longer time to go into extinction on the natural diet than on the other diets. There was no significant difference in extinction time among the other diet situations (Appendices 10-14).

The results of the extinction time for the various sexes on a no - food situation are presented in Table 3.22, Figure 24. In days to 100% extinction the various sexes did not differ in their extinction time. The males differed significantly from the females or the mixed sex in days to 80%, 60 - and 40% extinction while the females and the mixed sex did not differ in their extinction times. The mites irrespective of sex went into 20% extinction after the first day (Appendix 15).

The results of ANOVA on the extinction time of the mites under various confinement conditions are presented in Table 3.23, Figure 25. There were no significant differences in days to 100% extinction when the mites were confined with vaseline, talcum powder or without confinement (Appendix 16). There was, however, a slight insiginficant interaction between diet and confinement. The result of this interaction is shown in Figure 26. The solid diet seemed to do better with vaseline for confinement than with talcum powder or without confinement while the liquid diet did better without any confinement. But these differences were not statistically significant.

Table 3.21. ANOVA on Days To Percent Extinction of N. idaeus on 5 - Food Situations.

Source of variation	df	MS 100%	MS 80%	MS 60%	MS 40%	MS 20%
Between	4	611.25	527.75	340.95	103.386	16.70
within	40	38.88	37.25	21.885	17.74	2.88
Total	44					
SE (DMRT)		2.09	2.05	1.57	1.41	0.57
Means: A*		22.0^{a}* ± 4.02	19.1^{a} ± 3.96	15.3^{a} ± 3.04	8.9^{a} ± 2.77	4.1^{a} ± 1.10
B		4.6^{b} ± 0.48	3.0^{b} ± 0.49	2.3^{b} ± 0.15	2.0^{b} ± 0.15	1.1^{b} ± 0.10
C		8.3^{b} ± 0.84	4.4^{b} ± 0.72	3.6^{b} ± 0.64	2.2^{b} ± 0.42	1.5^{b} ± 0.22
D		2.2^{b} ± 0.20	1.2^{b} ± 0.13	1.0^{b} ± 0.00	1.0^{b} ± 0.00	1.0^{b} ± 0.00
E		4.6^{b} ± 0.67	2.6^{b} ± 0.60	1.8^{b} ± 0.37	1.4^{b} ± 0.24	1.2^{b} ± 0.20

*Means followed by the same letter are not significantly different at 5% level (DMRT).

Means A = Natural Diet
B = Artificial Liquid Diet
C = Artificial Solid Diet
D = No - Food Situation
E = Modified Artificial Liquid Diet.

(Mean ± SE) (Days).

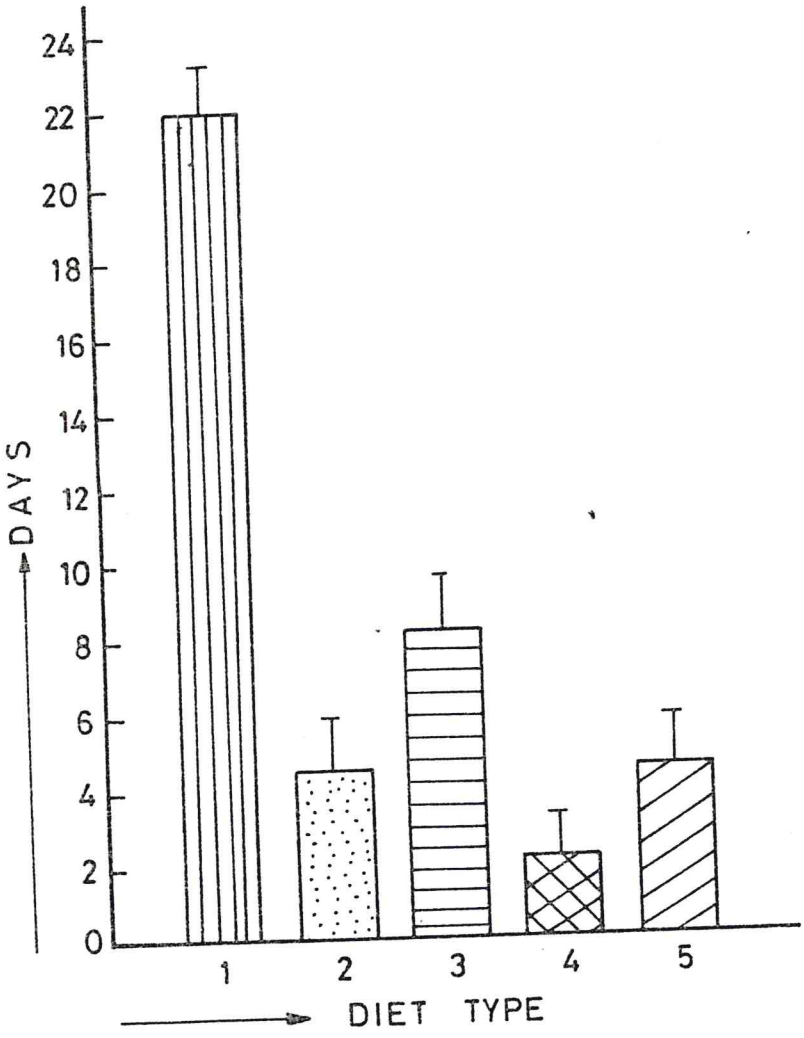

Fig. 19. Histogram showing days to 100% extinction of N. idaeus on natural-, artificial liquid-, artificial solid-, a no-food situation and a modified artificial liquid diets.

1 = natural diet; 2 = artificial liquid diet;
3 = artificial solid diet; 4 = a no-food situation;
5 = modified artificial liquid diet.

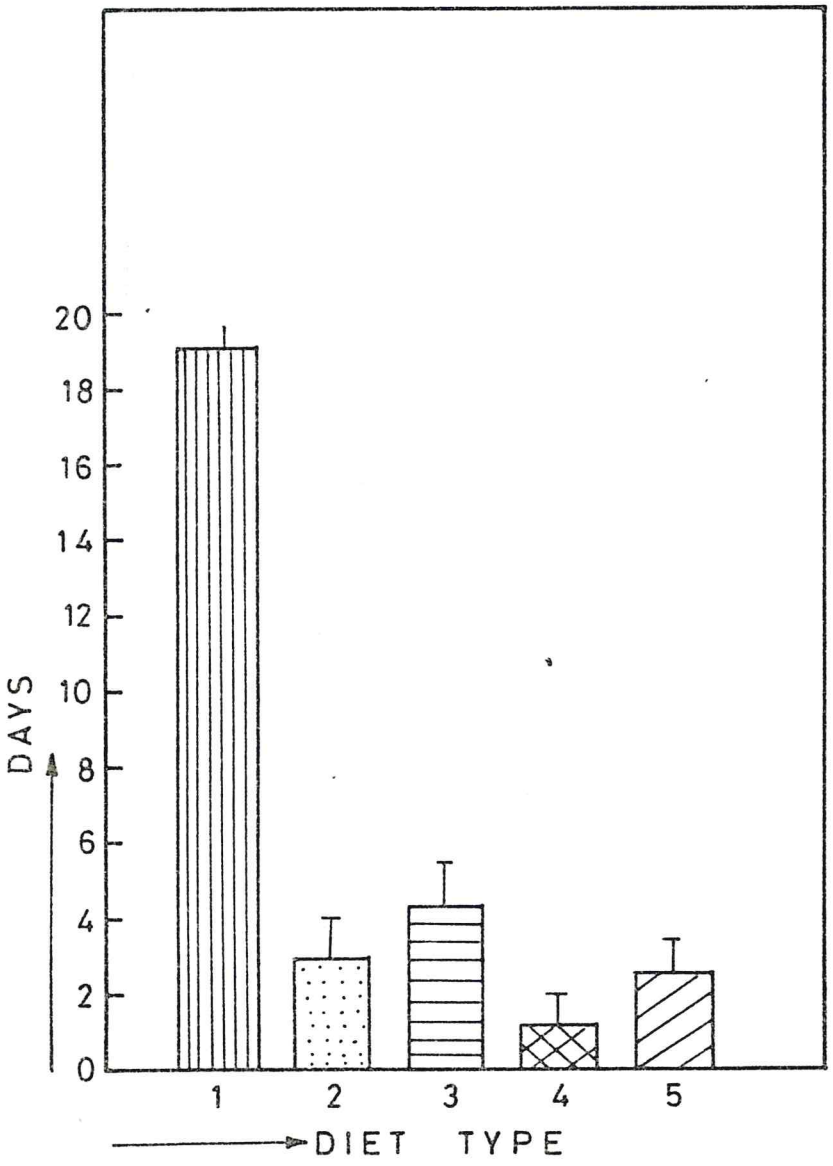

Fig. 20. Histogram showing days to 80% extinction of N. idaeus on the five diets.

1 = natural diet; 2 = artificial liquid diet;
3 = artificial solid diet; 4 = a no-food situation;
(5) modified artificial liquid diet.

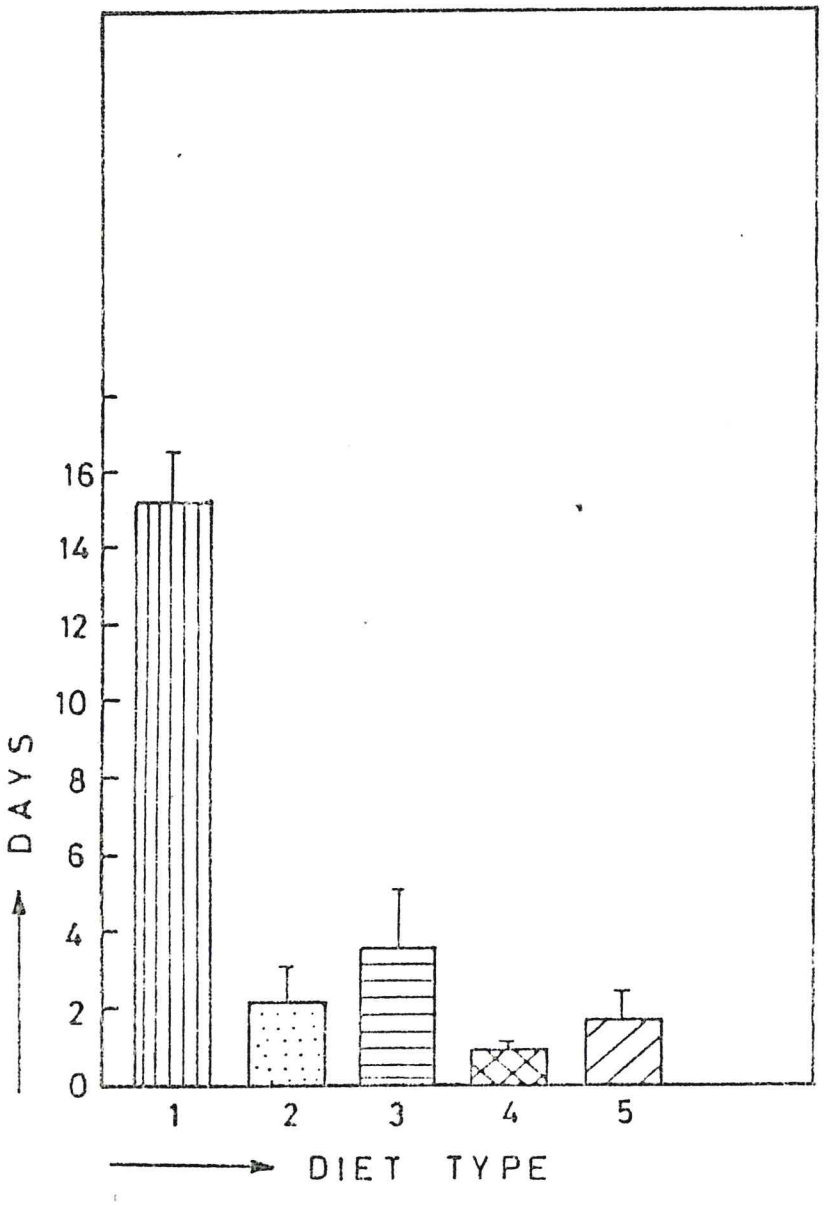

Fig. 21. Histogram showing days to 60% extinction of N. idaeus on the five diets

1 = natural diet; = artificial liquid diet;
3 = artificial solid diet; 4 = a no-food situation
5 = modified artificial liquid diet.

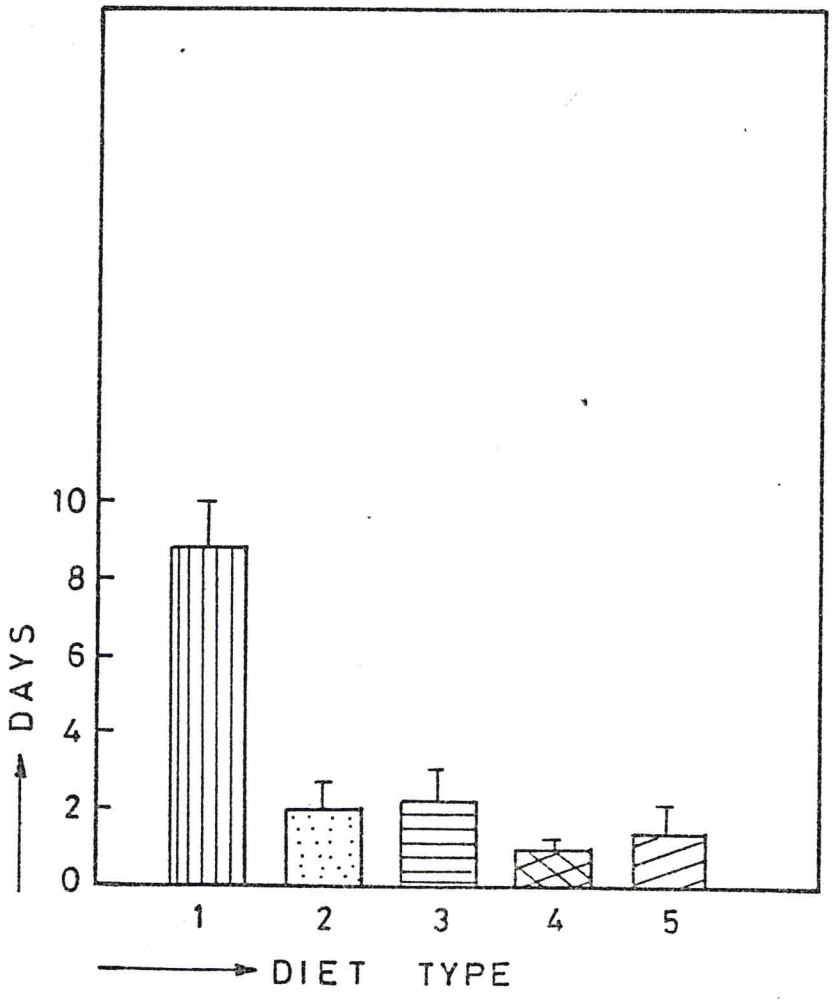

Fig. 22. Histogram showing days to 40% extinction of N. idaeus on the five diets.

1 = natural diet; 2 = artificial liquid diet;
3 = artificial solid diet; 4 = a no-food situation,
5 = modified artificial liquid diet.

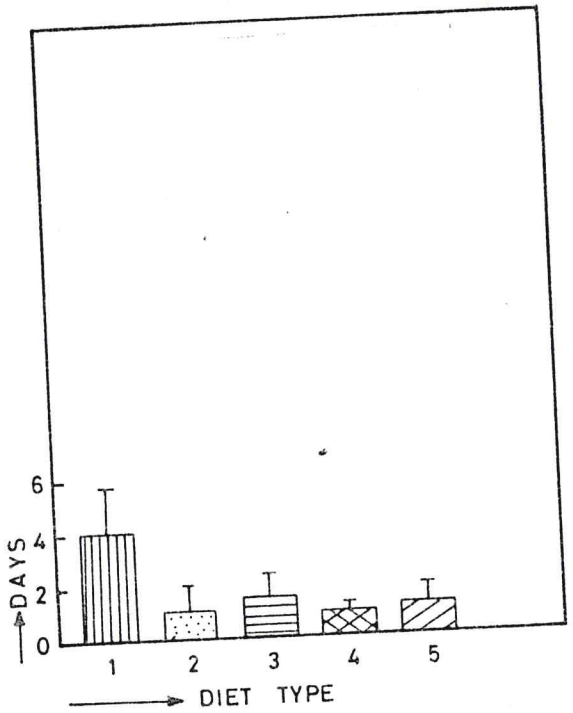

Fig. 23. Histogram showing days to 20% extinction of N. idaeus on the five diets. 1 = natural diet; 2 = artificial liquid diet; 3 = artificial solid diet; 4 = a no-food situation; 5 = modified artificial diet.

Table 3.22 ANOVA For Days To Percent Extinction of Males, Females and Mixed Sex of N. idaeus on a No - Food Situation.

Source of Variation	df	MS 100%	MS 80%	MS 60%	MS 40%
Between	2	1.23	3.63	3.23	0.433
Within	27	0.63	0.3	0.185	0.122
Total	29				
SE (DMRT)		NS	0.17	0.14	0.11
Means A		$2.6^{a} \pm 0.34$	$1.7^{b} \pm 0.21$	$1.3^{b} \pm 0.15$	$1.1^{b} \pm 0.10$
B		$2.9^{a} \pm 0.18$	$2.4^{a*} \pm 0.16$	$2.1^{a*} \pm 0.18$	$1.4^{a*} \pm 0.16$
C		$2.2^{a} \pm 0.2$	$1.2^{b} \pm 0.13$	$1.0^{b} \pm 0.00$	$1.0^{b} \pm 0.00$

* Means followed by the same letter are not significantly different at 5% level (DMRT)

Means: A = Females
B = Males
C = Mixed Sex (F + M)

NS = Not significant (ANOVA)

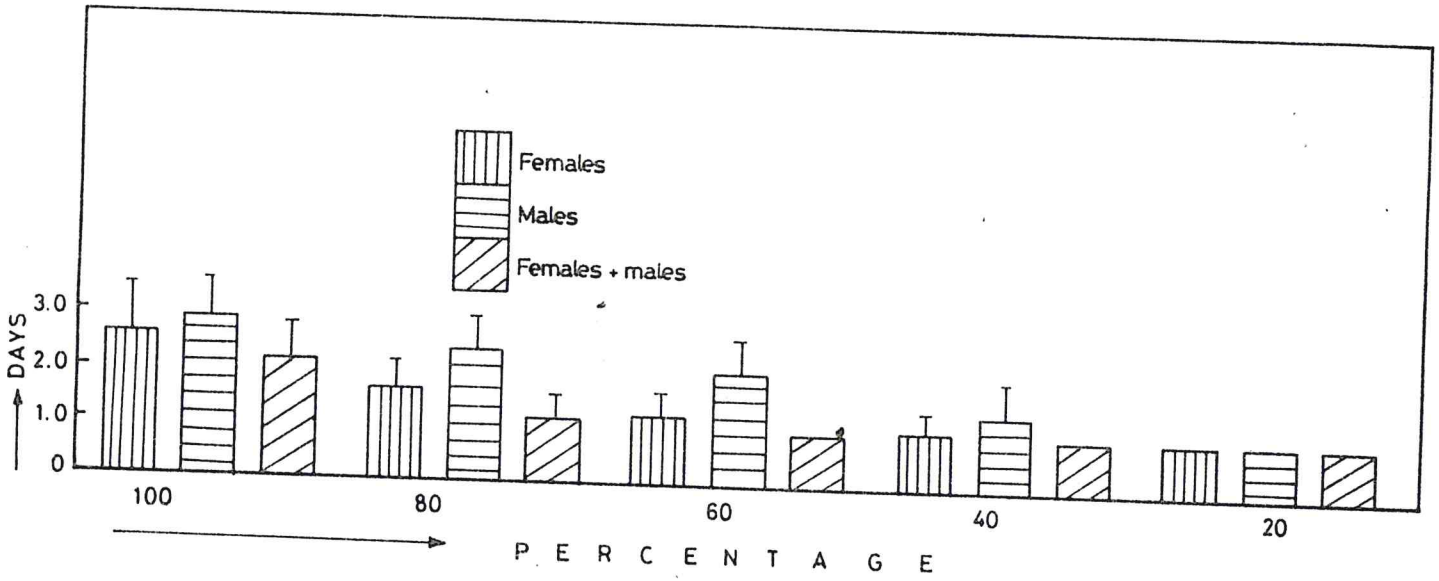

Fig. 24. Histogram showing days to percent extinction of males, females and mixed sex of N. idaeus on a no-food situation.

Table 3.23 ANOVA on Days to 100% Extinction of *N. idaeus* on the two artificial diets under different confinement conditions.

Source of Variation	df	SS	MS	F-ratio
Confinement	2	44.24	22.12	1.3 ns
Diet	1	38.4	38.4	2.28 ns
Diet x Confinement	2	33.69	16.85	3.16*
(Experimental Error)				
Sampling Error	54	287.6	5.33	

* Significant at 5% level.

ns = Not Significant.

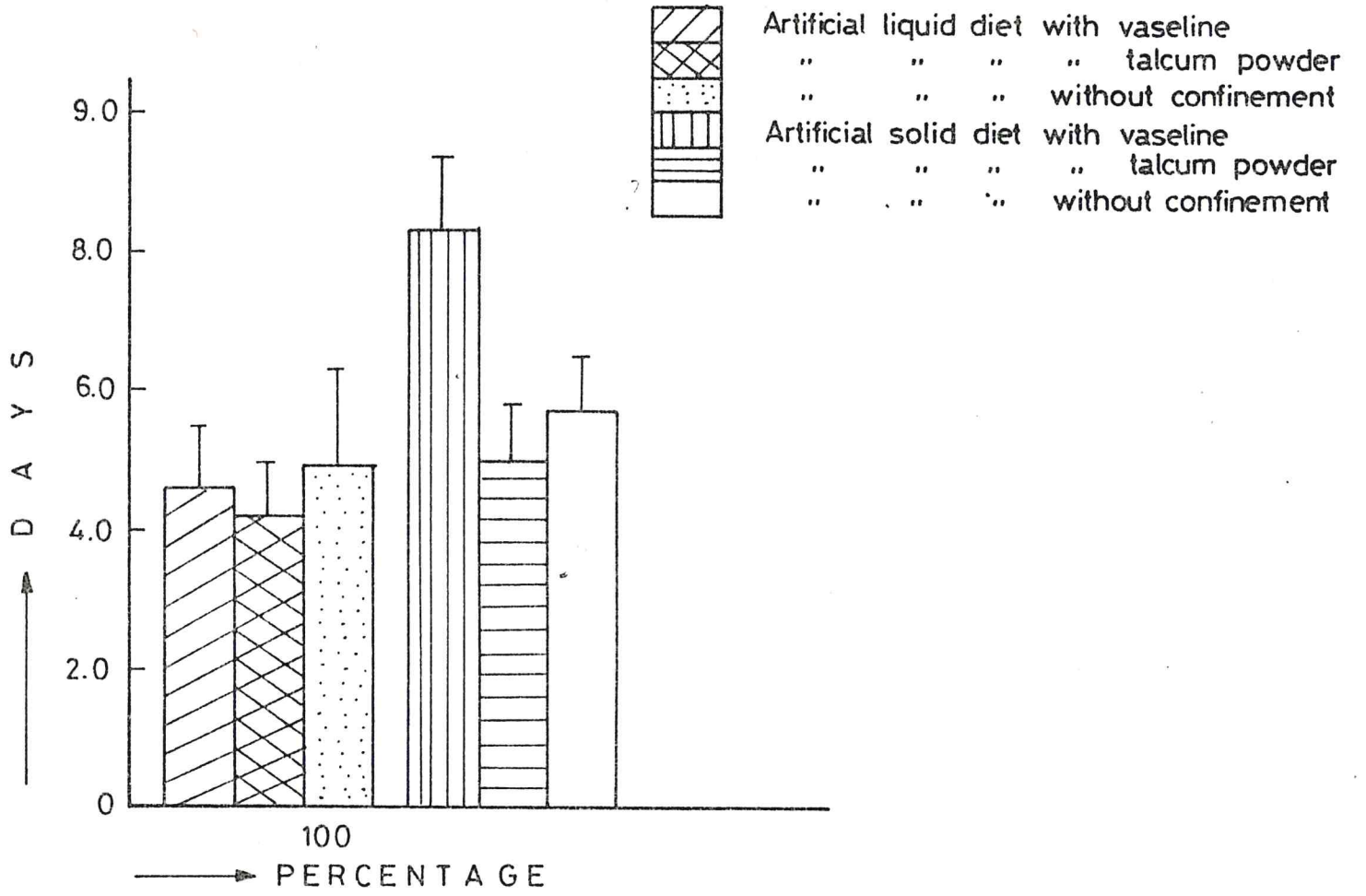

Fig. 25. Histogram showing days to 100% extinction of N. idaeus when confined with vaseline, talcum powder and without confinement on artificial liquid and artificial solid diets.

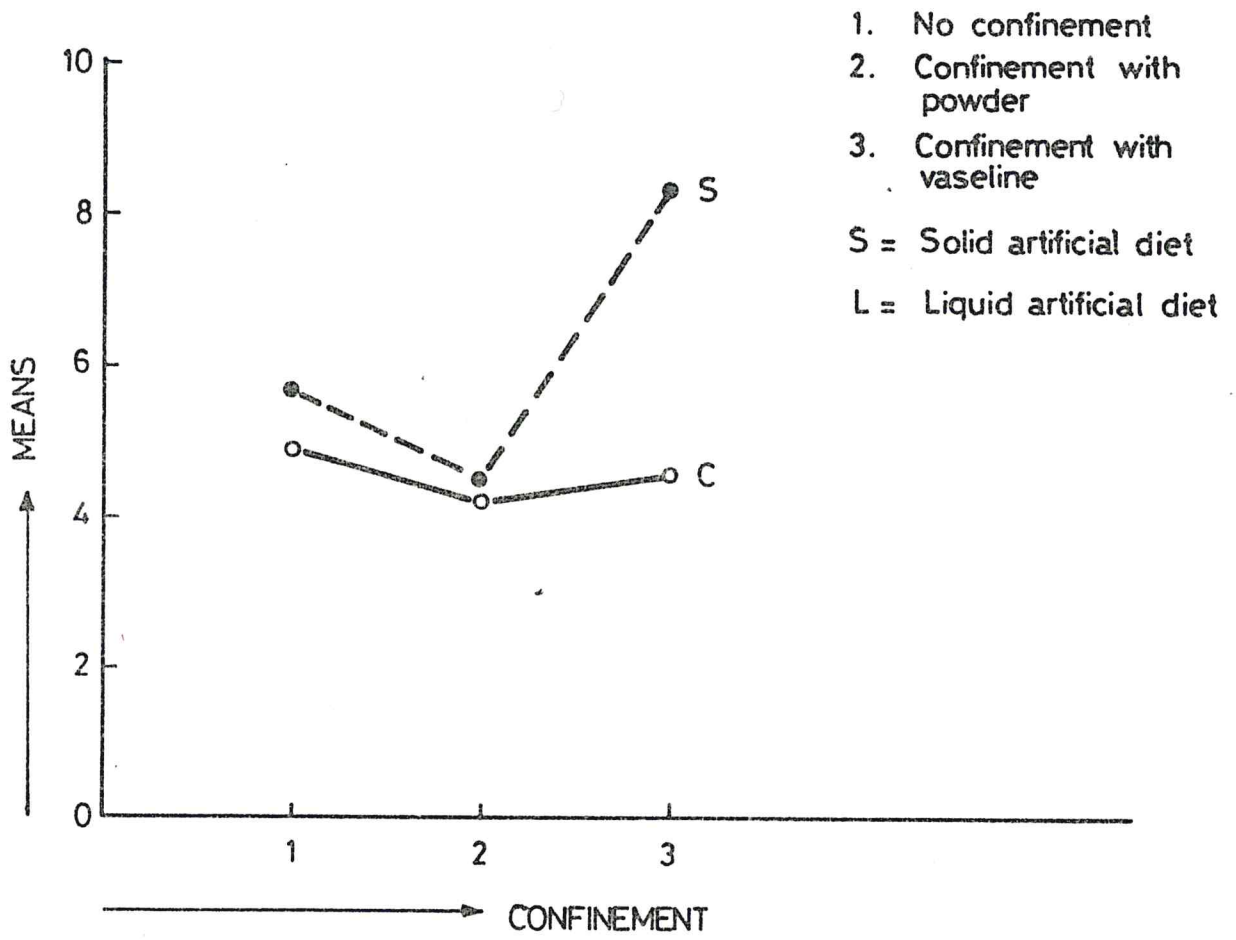

Fig. 26. Interaction between diet and confinement showing differences in days to 100% extinction on artificial liquid and artificial solid diets.

3.6 Feeding Behaviour

The results of preliminary tests to determine the average number of prey consumed by each stage of the predator per day are presented in Table 3.24. The number of prey consumed by each stage of the predator varied with the stage of the prey. But all the stages of the prey when offered individually as food were accepted by the feeding stages of the predator. The larval stage of the predator did not feed on any of the prey stages.

The results of feeding preference of the predator on various stages of the prey when these were offered together as food are presented in Table 3.25. The protonymphs and the deutonymphs of the predator ate more of the eggs and the juvenile stages of the prey than the adult stages. The adult females and males of the predator ate more of the eggs and the males of the prey and ate few of the larvae. Using Shannon's Index of Diversity and Pieulou's Index (Shannon and Weaver, 1949; Pielou, 1975) there was high preference towards the eggs and the juvenile stages of the prey by the protonymphs and the deutonymphs of the predator and towards the eggs and the male prey stages by males and females of the predator. T-test showed that there was no difference in prey stage preference between the protonymphs and the deutonymphs -, and the males and female adults of the predator (t alpha 0.025 df $\geq$100) (Zar, 1974).

Table 3.24 The Average Number of Prey Consumed Per Predator Per Day (Mean ± SE).

Prey Stage	Predator				
	Larva	Protonymph	Deutonymph	Ad. Female	Ad. Male
Egg	0.00	5.2 ± 0.41	4.65 ± 0.47	9.45 ± 0.77	6.65 ± 0.71
Larva	0.00	1.94 ± 0.19	2.28 ± 0.21	2.25 ± 0.28	2.05 ± 0.24
Protonymph	0.00	1.89 ± 0.18	2.11 ± 0.21	2.68 ± 0.29	1.60 ± 0.16
Deutonymph	0.00	1.24 ± 0.11	2.11 ± 0.20	3.30 ± 0.28	1.45 ± 0.14
Adult Male	0.00	1.25 ± 0.11	2.20 ± 0.24	3.65 ± 0.23	2.60 ± 0.17
Adult Female	0.00	1.0 ± 0.00	1.56 ± 0.20	2.50 ± 0.25	1.24 ± 0.12

Table 3.25 Feeding Preference of N. idaeus on Various Stages of the Prey.

Prey Stage	Predator			
	Protonymph	Deutonymph	Adult Female	Adult Male
Egg	20	19	21	21
Larva	12	11	3	3
Protonymph	11	10	6	5
Deutonymph	5	4	7	9
Adult Male	3	7	12	11
Adult Female	0	1	2	4
Total	51	52	51	53
H	0.364	0.394	0.388	0.397
Hmax	0.778	0.778	0.778	0.778
J	0.468	0.506	0.499	0.510
DF	101		104	
T-tab	1.984		1.984	
T-cal	- 0.037		- 0.010	

H = Shannon's Index of Diversity (Shannon and Weaver, 1949).

J = Pielou's Index (Pielou, 1975).

Hmax = Log K = Log 6

3.7 Cannibalism

Results of experiments on cannibalism revealed that in the absence of the prey the adults of N. idaeus fed on their own eggs and young ones but not on themselves. The confined nymphs of the predator consumed both the larvae and the eggs. The deutonymphs of the predator attacked and consumed the protonymphs of their own species. When the predator returned to the prey and consumed all the stages there was no interference to their own species.

3.8 Mortality

Transformed figures of the results of mortality of N. idaeus at different stages of development for twelve generations are presented in Table 3.26 Figures 27 and 28. The stage of development at which mortality occurred highest was the adult stage, and this contributed most to the total mortality as shown in Figure 29. Correlation analysis showed that the adult stage was very positively correlated with Total K. The egg and the larval stages contributed least to the total mortality as shown in Table 3.26, last row. The key-factor causing mortality is shown in Figure 28. The relationship between each stage and the key-factor is presented in Figures 30-34.

3.9 Life Table for N. idaeus

The Life Tables constructed for N. idaeus showing age-specific fecundity and survival rates are presented in

Table 3.26 Mortality of different stages of N. idaeus for twelve generations.

Generations	EK_0	LK_1	PK_2	DK_3	AK_4	TK
1	0.01	0.00	0.00	0.00	0.00	0.01
2	0.00	0.00	0.01	0.00	0.02	0.03
3	0.03	0.01	0.00	0.02	0.04	0.10
4	0.01	0.05	0.03	0.03	0.05	0.17
5	0.00	0.02	0.01	0.03	0.00	0.06
6	0.00	0.00	0.05	0.02	0.04	0.11
7	0.02	0.01	0.00	0.04	0.03	0.10
8	0.01	0.00	0.02	0.00	0.05	0.08
9	0.00	0.00	0.02	0.03	0.11	0.15
10	0.04	0.00	0.01	0.00	0.03	0.08
11	0.00	0.00	0.02	0.02	0.03	0.07
12	0.00	0.01	0.04	0.03	0.03	0.11
Mean	0.01	0.0083	0.0175	0.0183	0.0358	0.0892
SE (±)	0.0039	0.0042	0.0046	0.0042	0.0082	0.5692
Correlation with total K =	0.015	0.532	0.499	0.642	0.740	

Key: EKo = Egg Mortality
LK1 = Larval Mortality
PK2 = Protonymphal Mortality
DK3 = Deutonymphal Mortality
AK4 = Adult Mortality
TK = Total Mortality = Key Factor. = $k_0 + k_1 + k_2 + k_3 + k_4 = K$

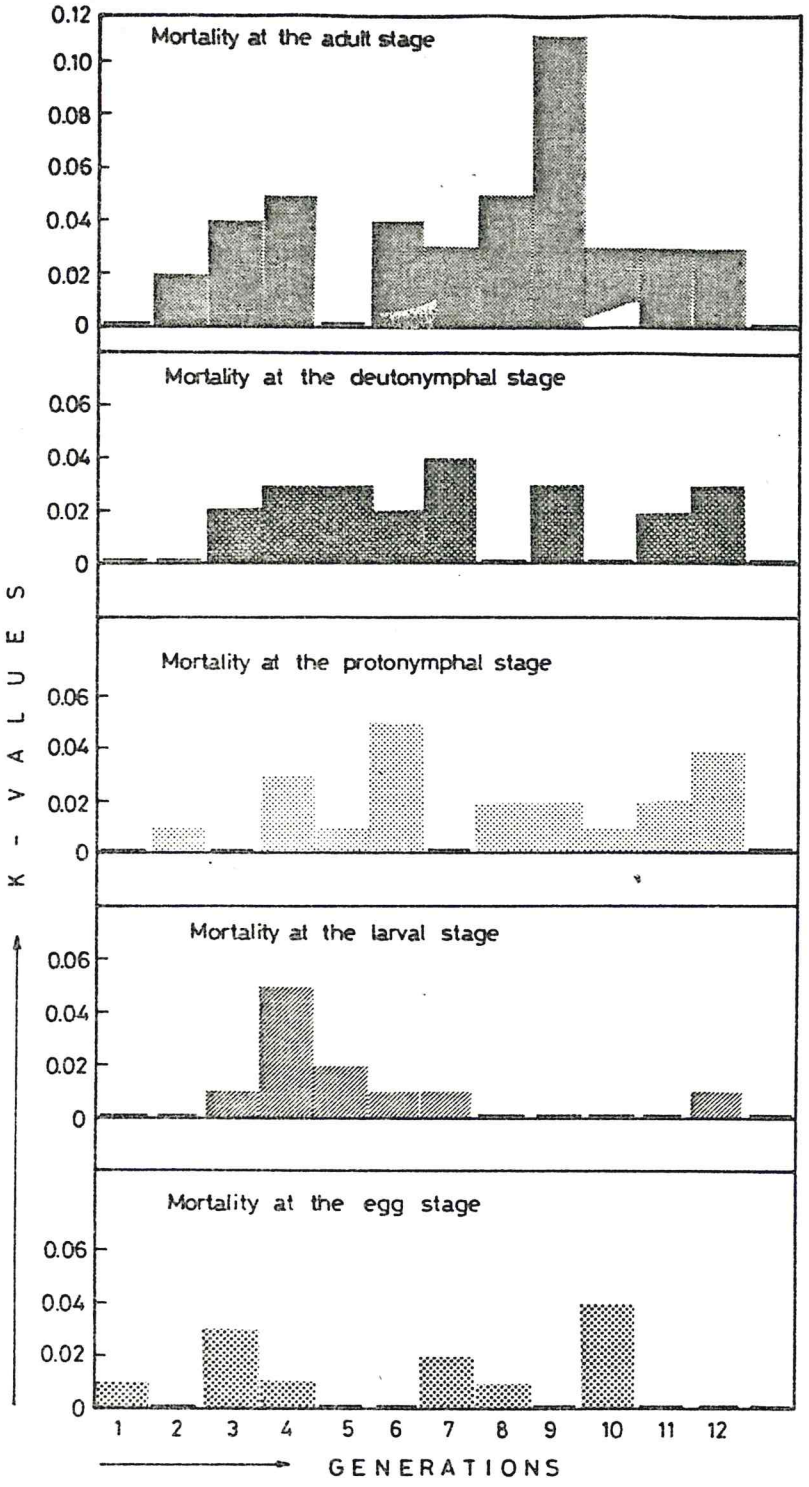

Fig. 27. Histogram showing mortality in N. idaeus at different stages of development for 12 generations.

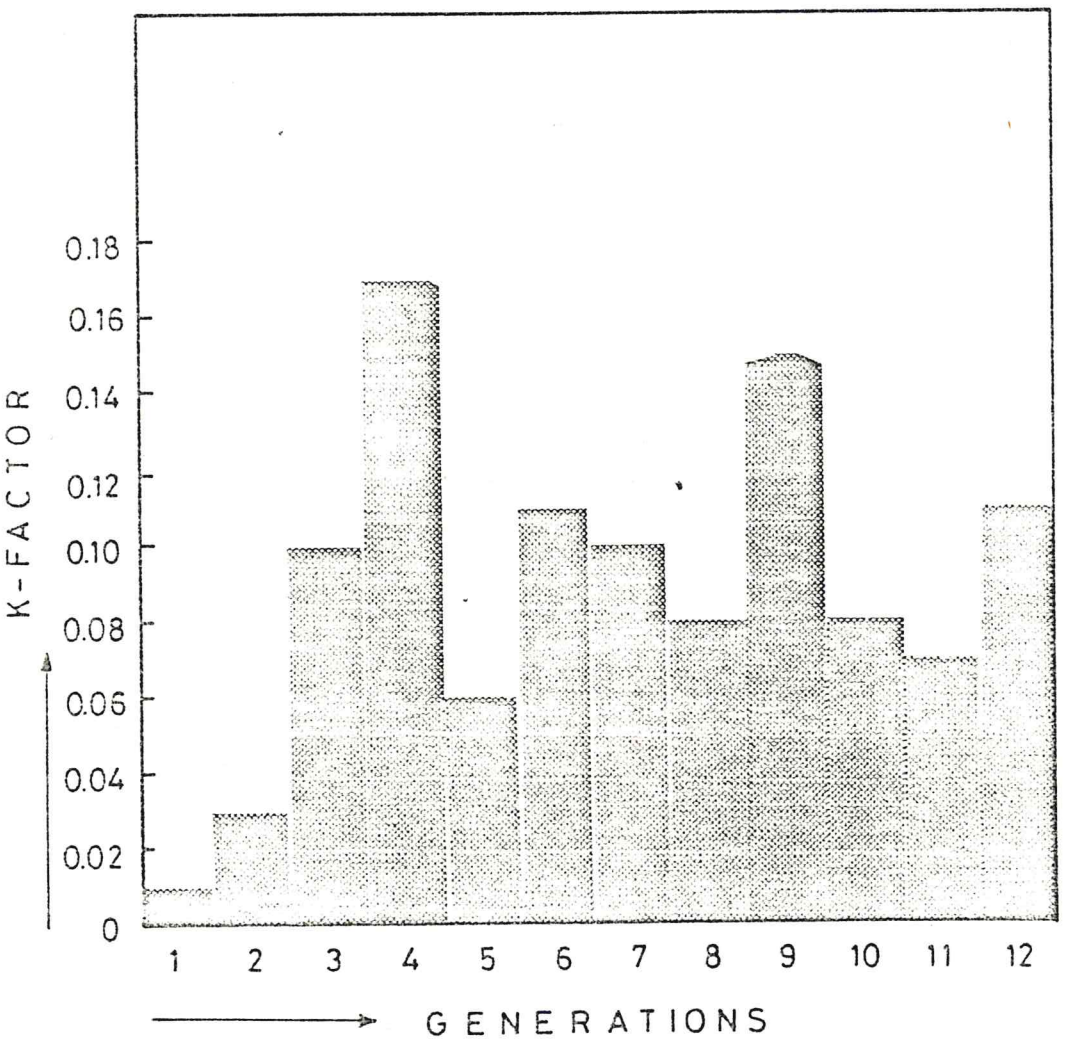

Fig. 28. Key-factor causing mortality for 12 generations.

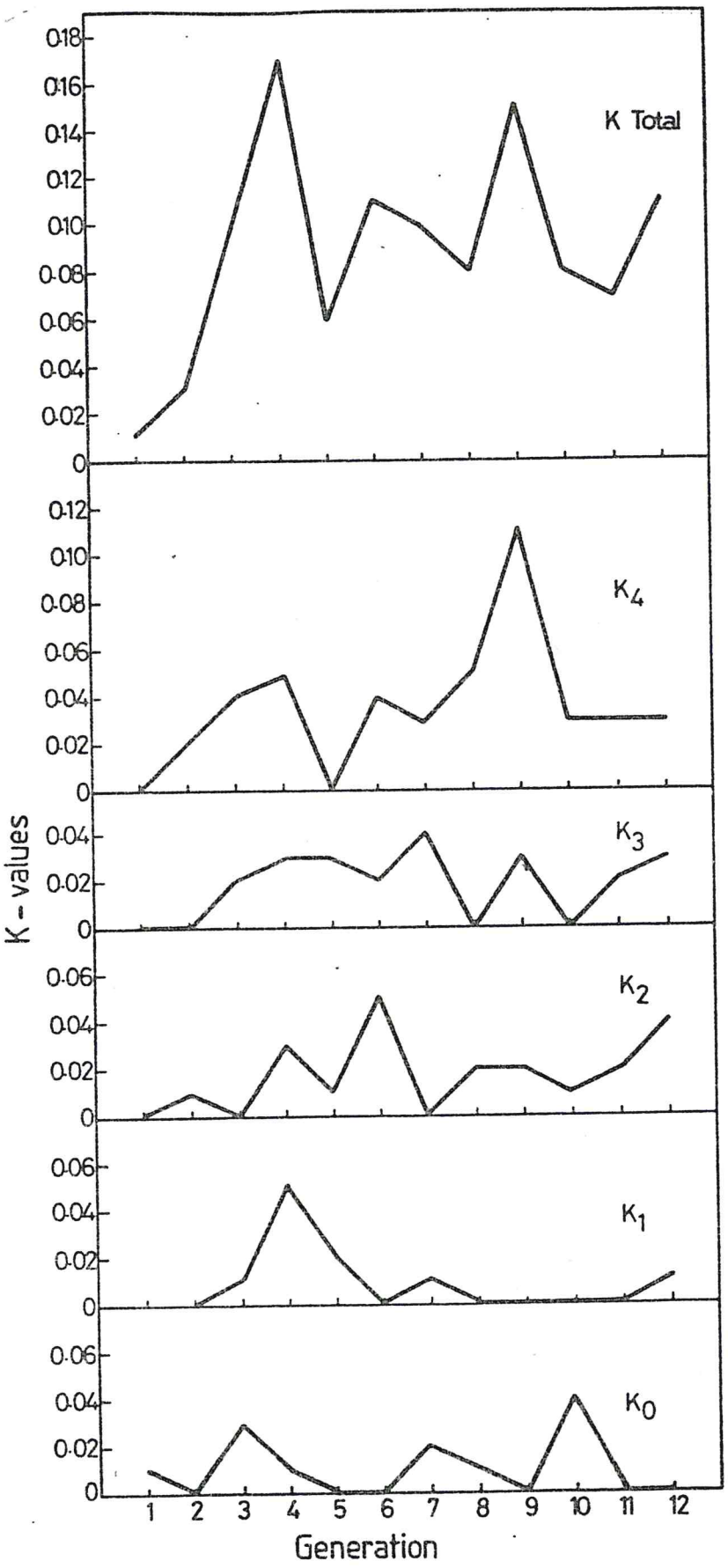

Fig. 29. Graph of the Key-factor analysis of the mortality of N. idaeus at each stage of development for 12 generations.

K_o = egg stage; K_1 = larval stage; K_2 = protonymph stage;

K_3 = deutonymph stage; K_4 = adult stage,

K Total = Key-factor.

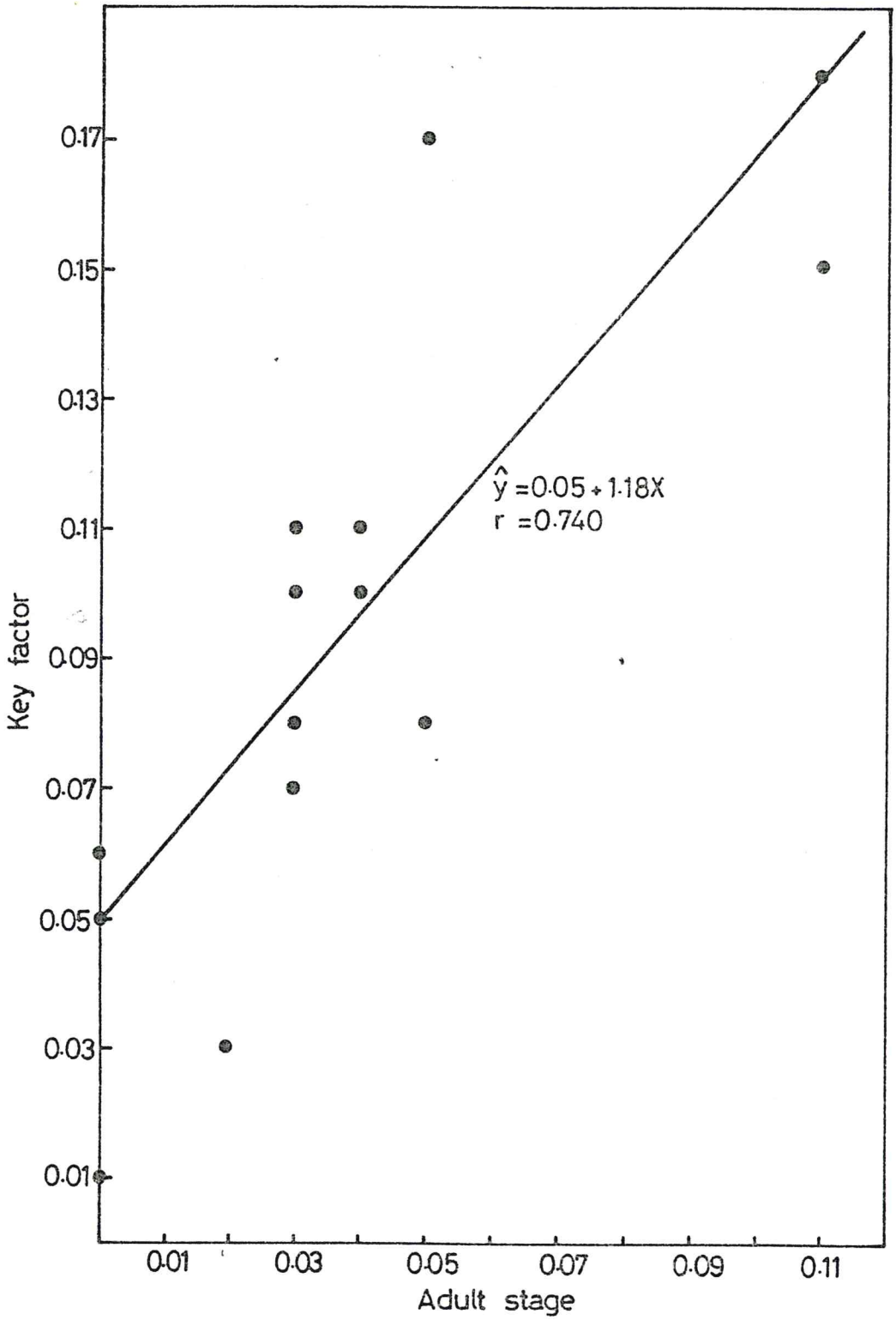

Fig. 30. The relationship between the adult stage and the key-factor.

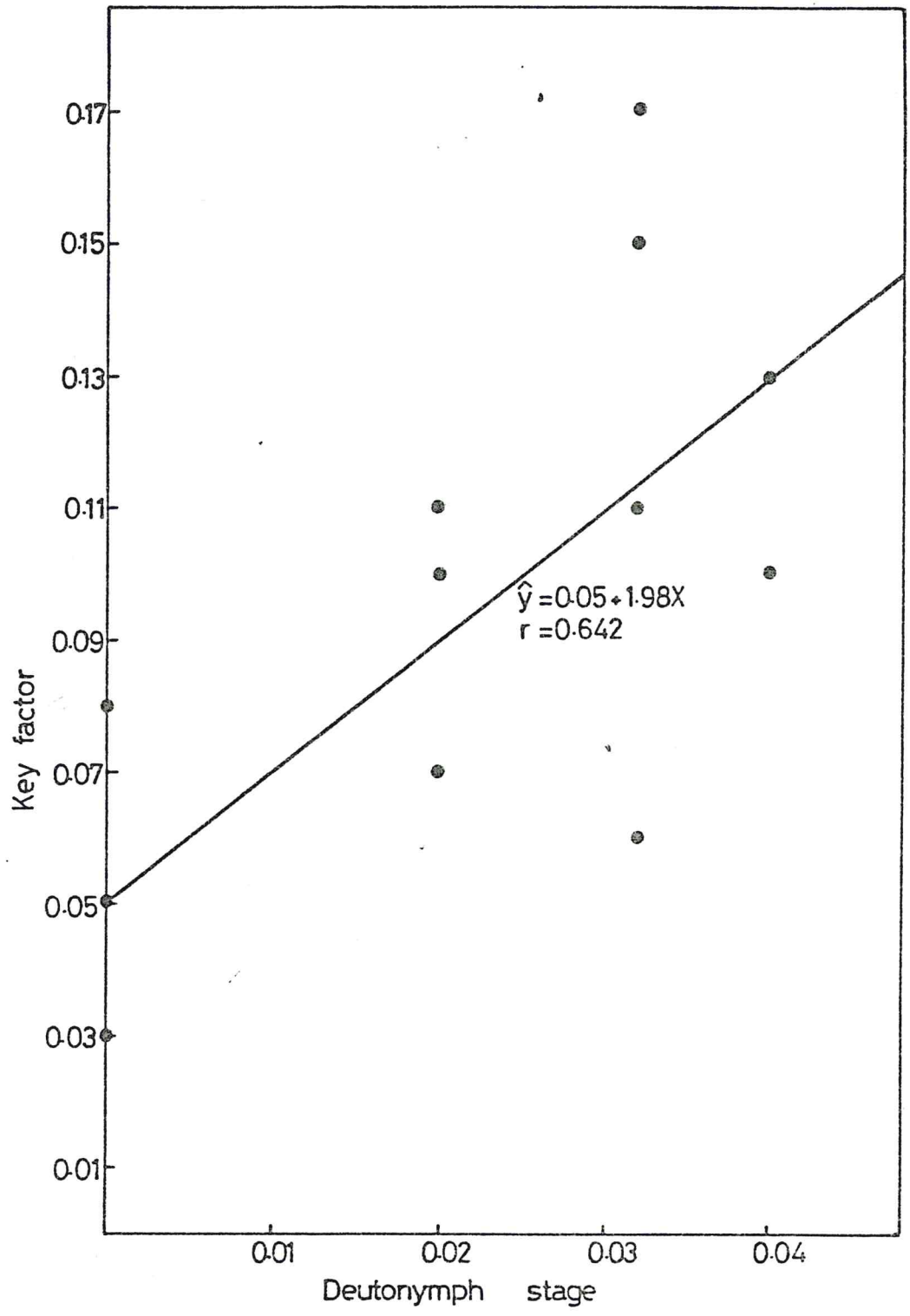

Fig. 31. The relationship between the deutonymph stage and the Key-factor.

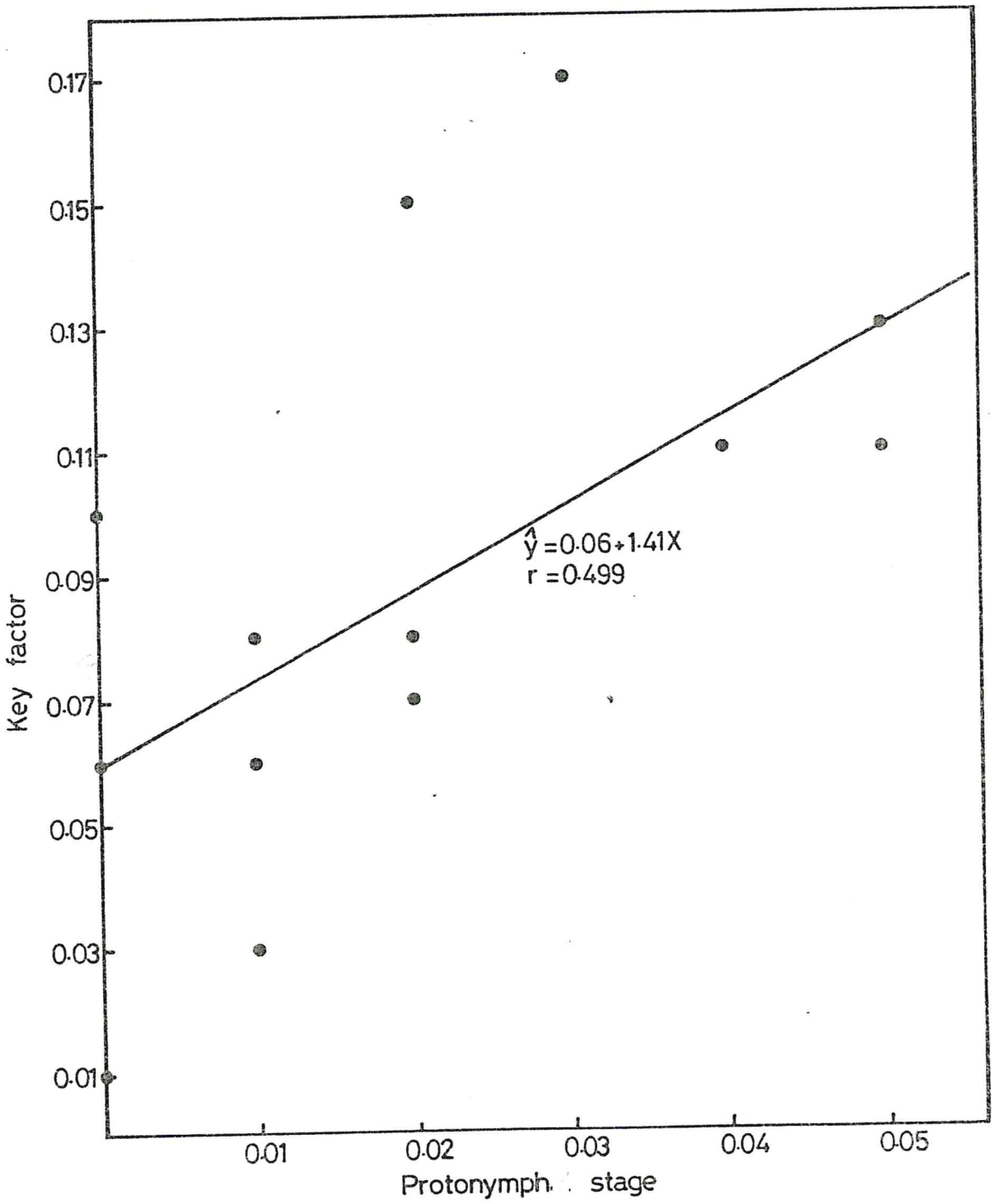

Fig. 32. The relationship between the protonymph stage and the Key-factor.

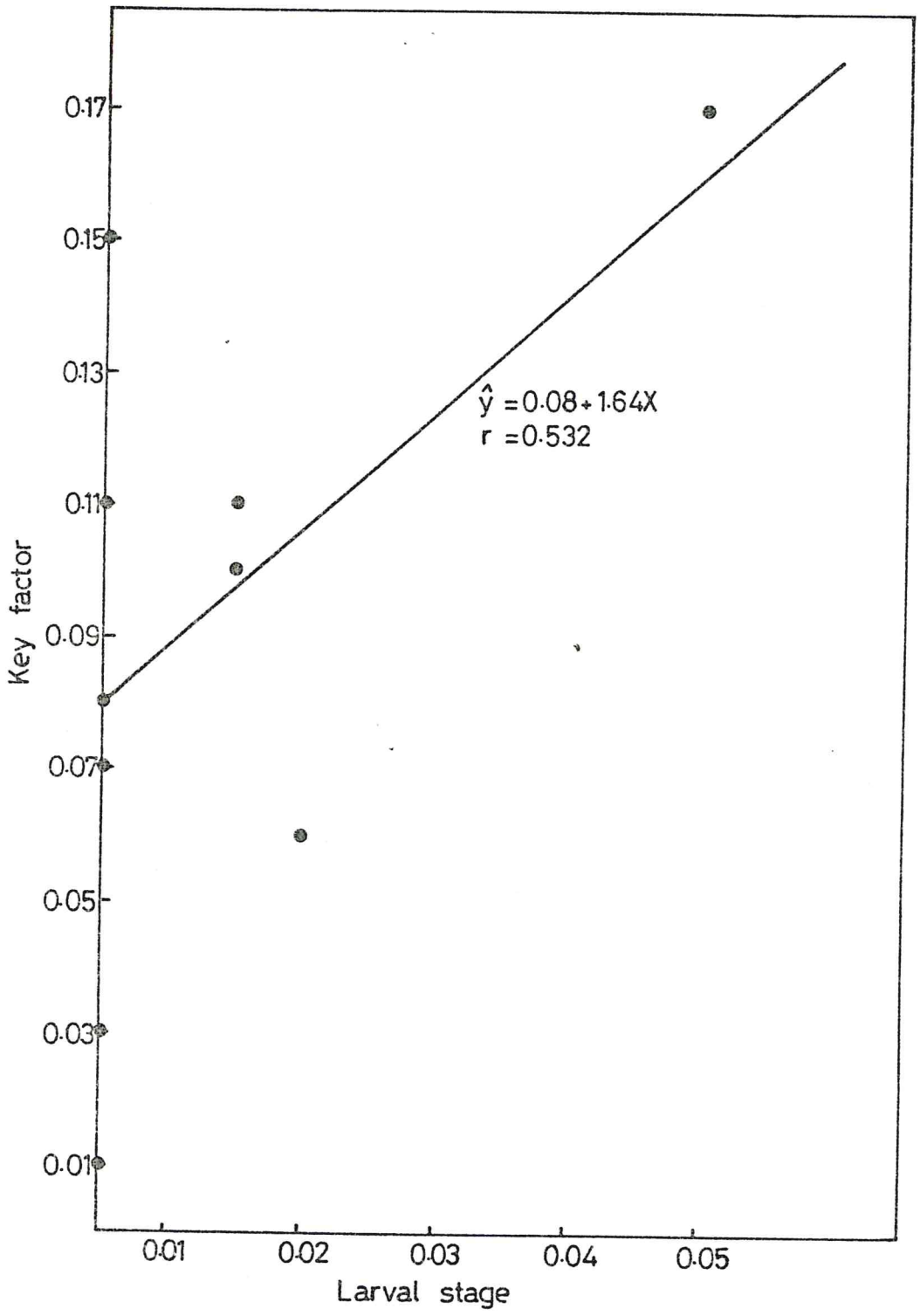

Fig. 33. The relationship between the larval stage and the key-factor.

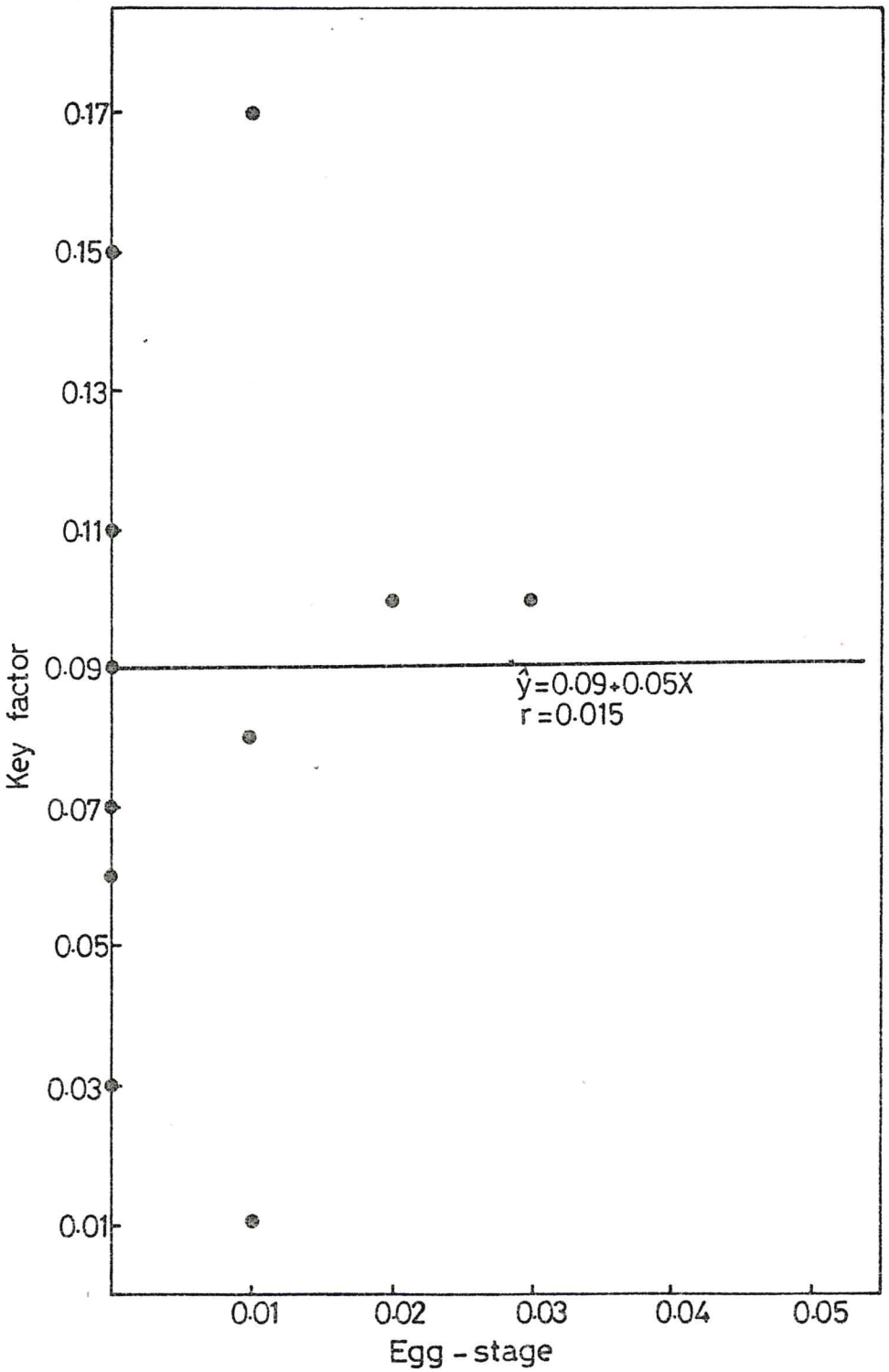

Fig. 34. The relationship between the egg stage and the key factor.

Tables 3.27 and 3.28. The rough estimates of T (=TC) and r_m (=rc) (Pielou, 1977) for the two tables are 6.50 days and 0.384 per female per fay for 1 and 6.06 days and o.34 per female per day for 2. (Tc is the pivotal age).

The results of the accurate estimates indicating the actual rate of natural population increase are presented below:

For life table 1, r_m = 0.845 per head per day

Ro = 12.15 individuals/generation

Lambda (λ) = 2.328

T = 2.969 days

and for life table 2,

r_m = 0.690 per head per day

Ro = 7.71 individuals/generation

Lambda (λ) = 1.993

T = 2.958 days

where r_m, Ro, Lambda (λ) and T are as defined in Materials and Methods.

Table 3.27 Life Table of N. idaeus. 1.

X (Days)	Lx	Mx	LxMx	XLxMx
1	1.00	1.19	1.19	1.19
2	1.00	1.19	1.19	2.38
3	1.00	1.19	1.19	3.57
4	1.00	1.44	1.44	5.76
5	0.93	1.44	1.34	6.70
6	0.71	1.83	1.30	7.80
7	0.57	1.83	1.04	7.28
8	0.57	1.14	0.65	5.20
9	0.43	1.14	0.49	4.41
10	0.43	0.67	0.29	2.90
11	0.43	0.67	0.29	3.19
12	0.43	0.67	0.29	3.48
13	0.43	0.67	0.29	3.77
14	0.29	0.50	0.15	2.10
15	0.29	0.50	0.15	2.25
16	0.21	0.50	0.11	1.76
17	0.21	0.50	0.11	1.87
18	0.21	0.33	0.07	1.26
19	0.21	0.33	0.07	1.33
20	0.21	0.80	0.17	3.40
21	0.14	0.80	0.11	2.31
22	0.14	0.50	0.07	1.54
23	0.14	0.50	0.07	1.61
24	0.14	0.25	0.04	0.96
25	0.14	0.25	0.04	1.00
26	0.07	0.00	0.00	0.00
		20.83	Σ 12.15	Σ 79.02

X = Age of individuals in days

Lx = No. of individuals alive at age "X" as a proportion of 1

Mx = No. of female offspring produced per female in the age interval "X"

Table 3.28 Life Table of N. idaeus. 2.

X (Days)	Lx	Mx	LxMx	XLxMx
0	1.00	0.00	0.00	0.00
1	1.00	1.11	1.11	1.11
2	1.00	1.11	1.11	2.22
3	0.70	1.11	0.78	2.34
4	0.70	0.75	0.53	2.12
5	0.70	0.75	0.53	2.65
6	0.60	0.75	0.45	2.70
7	0.60	1.00	0.60	4.20
8	0.60	1.00	0.60	4.80
9	0.60	0.89	0.53	4.77
10	0.30	0.89	0.27	2.70
11	0.30	1.20	0.36	3.96
12	0.20	1.20	0.24	2.88
13	0.20	0.25	0.05	0.65
14	0.20	0.25	0.05	0.70
15	0.20	0.50	0.10	1.50
16	0.20	0.50	0.10	1.60
17	0.20	0.25	0.05	0.85
18	0.20	0.25	0.05	0.90
19	0.20	0.33	0.07	1.33
20	0.10	0.33	0.03	0.60
21	0.10	0.50	0.05	1.05
22	0.10	0.50	0.05	1.10
23	0.10	0.00	0.00	0.00
		15.42	$\sum$ 7.71	$\sum$ 46.73

X = Age of individuals in days
Lx = No. of individuals alive at age "X" as a proportion of 1
Mx = No. of female offspring produced per female in the age interval "X"

4. DISCUSSION

4.1 Life Cycle and Development

Observations on the life cycle of N. idaeus in this study agree with those reported in the literature in respect of phytoseiids generally (Sabelis, 1985). But these differ from the observations reported for A. fallacis (Ballard, 1954) in which the males did not pass through the deutonymph stage before attaining adulthood.

The oval shape of the eggs is characteristic of a number of phytoseiids including P. persimilis, M. occidentalis, T. occidentalis, A. umbraticus, A. citrifolius, and A. fustis (Laing, 1968, 1969; Lee and Davis, 1968; Knisley and Swift, 1971; De Moraes and McMurtry, 1981; Ezulike and Odebiyi, 1985). But it differs from that of T. floridanus whose eggs are slightly tapered from one pole to the other (Tanigoshi and McMurtry, 1977). Such specific differences are, perhaps, not unexpected. Similarly the translucent colour of the eggs when freshly laid is similar to that of most phytoseiids, but differs from the others such as P. macropilis, P. persimilis and A. fustis as incubation progresses (Prasad, 1967; Laing, 1968; Ezulike and Odebiyi, 1985). The eggs of these phytoseiids change colour depending on the type of prey offered to the ovipositing female whereas that of N. idaeus retains its colour till hatching, except the black oblique lines that run across the egg

chorion towards the time of eclosion. These lines are said to represent the rudiments of the appendages as observed in A. citrifolius (De Moraes and McMurtry, 1981).

So the type of food offered to the ovipositing female of N. idaeus did not affect the colour of its eggs. These differences could be specific. They could also be dependent on the type of prey offered to the ovipositing female.

The egg laying habit of N. idaeus is similar to that of P. macropilis, T. tiliae and Typhlodromus soleiger (Ribaga) (Collyer, 1956), but different from that reported by Ballard (1954) for A. fallacis and by Tanigoshi and McMurtry (1977) for T. floridanus.

A sticky substance observed on the surface of the egg of N. idaeus is common to phytoseiids as reported in the literature. During eclosion the first pair of legs appear first through the egg chorion followed by the gnathosomal appendages. Similar observation was reported by Prasad (1967) for P. macropilis, and Lee and Davis (1968) for T. occidentalis. Eclosion time is somewhat similar to that of A. citrifolius (De Moraes and McMurtry, 1981), but differs from that of A. fallacis, P. macropilis and T. occidentalis (Ballard, 1954; Prasad, 1967; Lee and Davis, 1968). These differences might be specific and due, probably, to general experimental conditions. This could also be responsible for the

difference in the incubation period of N. idaeus and that reported for other phytoseiids in the literature.

In N. idaeus, the larva did not feed. This observation agrees with a similar phenomenon reported by several authors (see literature review P. 3), but differs from the report of others such as McMurtry and Scriven (1964) for T. rickeri, Prasad (1967) for P. macropilis, Laing (1968) for P. persimilis and McMurtry (1977) for T. persianus. These differences might also be specific. Non-feeding in the larval stage might be advantageous as it could reduce the possibility of intraspecific competition and enable the more effective sharing of the same habitat with the other stages of the same species.

The young stages of N. idaeus were observed to go into distinct quiescent stages. This observation is similar to that reported for A. citrifolius (De Moraes and McMurtry, 1981), and A. teke (Ochieng et al., 1987) The period of quiescence differs from that reported for other phytoseiids (Ballard, 1954; Laing, 1968; Croft and Jorgensen, 1969; Knisley and Swift, 1971; Sanderson and McMurtry, 1984; Ezulike and Odebiyi, 1985). These differences might be specific and due to the general experimental conditions as well as in the system of observation.

N. idaeus did not develop beyond the protonymph stage on the artificial diets. This observation is

contrary to the results reported by Ochieng et al. (1987) for A. teke on the same diet. The inability of N. idaeus to develop on the artificial diet might be that it did not feed on the diet. Food is required for growth and development of phytoseiids (Sabelis, 1985). Some artificial diets might not be suitable to sustain growth beyond the protonymph stage. Perhaps a modification of the diet, or a completely new formulation based on the nutrient quality of the tetranychid mites might be able to sustain the growth of this mite beyond the stage observed in the present study. The observed difference in the response of the two phytoseiids to the same diet might be specific as stated earlier. The results obtained in the present study also differ from those obtained in respect of A. limonicus, A. hibisci, T. occidentalis, and T. rickeri (McMurtry and Scriven, 1966). They also differ from the results of Shehata and Weismann (1972) for P. persimilis and M. occidentalis. These differences might also be specific and due perhaps to the differences in the diet formulation.

The moulting process observed in N. idaeus in which the old exoskeleton is ruptured transversely on the dorsum by various movements of the body agrees with previous observations made by various authors, but differs from that reported for A. fallacis, T. occidentalis and A. citrifolius (Ballard, 1954; Lee and Davis, 1968; De Moraes and McMurtry, 1981). These differences might also be specific.

Moulting in N. idaeus takes place at any time. This observation agrees with the account given in most phytoseiid mites (Sabelis, 1985) except A. vazimba (Blommers, 1974). This difference might also be specific. No similar observation has been reported in the literature.

The colour of the protonymphs is similar to that reported for A. fallacis, T. occidentalis and P. fotheringhamiae (Ballard, 1954; Lee and Davis, 1968; Schicha, 1975).

The development period of the protonymphs and the deutonymphs is similar to that reported by Ochieng et al. (1987) for A. teke but different from that reported for other phytoseiids. Similarly the developmental time (egg-egg) also differs from that reported for other phytoseiids. These differences might be due to varying experimental conditions. In most cases, the temperatures and the relative humidities used by most authors were lower than the ones used in this study. Development time has been shown to decrease with increasing temperature (Smith and Newsom, 1970; Blommers, 1976; De Moraes and McMurtry, 1981; Krishnamoorthy, 1982). Thus the higher temperature used in the present study might have been responsible for the shorter development time observed in N. idaeus. The faster development of males is similar to that reported for A. gossypii, P. persimilis, A. andersoni, and A. fustis (ElBadry and El-Banhawy, 1968;

Amano and Chant, 1977; Ezulike and Odebiyi, 1985), but different from that reported for A. umbraticus whose females develop faster than the males (Knisley and Swift, 1971). Faster development of males is considered advantageous for successful mating immediately the females reach the adult stage.

The size of the males conforms to that generally reported for phytoseiids, but the colour differs. The light orange colour of the female also differs from the others. Similarly the preoviposition period is also different from that reported for many phytoseiids, including that by Dinh et al. (1987) for the same species. These differences might probably be due to varying experimental conditions and in the system of observation.

Females of N. idaeus did not oviposit without mating. This is similar to the observations made in respect of other phytoseiids, generally.

4.2 Measurements of the Various Life Stages

The size of the egg of N. idaeus differs from that reported for other phytoseiids (Ballard 1954; Lee and Davis, 1968; Prasad, 1973; Ezulike and Odebiyi, 1985). The length of the egg, however, agrees with that reported for A. umbraticus (Knisley and Swift, 1971). Furthermore, the size of the adult females also differs from that reported by various authors (see Womersely, 1954; Denmark

and Muma, 1973; McMurtry, 1977; Matthysse and Denmark, 1981; De Moraes and McMurtry, 1983; Congdon, and McMurtry, 1985). These differences might be species specific and due, perhaps, to the system of measurements used and the ages of the mites. However, the adult size observed in the present study is within the range stated generally for phytoseiids (Womersely, 1954; Chant, 1985; Sabelis, 1985).

4.3 Fecundity and Sex Ratio

The failure of N. idaeus to develop and oviposit on the artificial diets differs from the observation reported for A. teke on the same diet by Ochieng et al. (1987). This difference might be specific. A. teke is a native phytoseiid mite while N. idaeus is exotic. The observed failure also differs from the observation reported for A. limonicus, A. hibisci, T. occidentalis, and T. rickeri by McMurtry and Scriven (1966), and P. persimilis by Shehata and Weismann (1972). It also differs from the observation reported for A. largoensis, I. degenerans, and T. pyri by Kennett and Hamai (1980). These differences might be both specific and probably due to the differences in the diet formulation. However, the failure of N. idaeus to develop and oviposit on the artificial diets agrees with the results obtained in respect of P. persimilis and M. occidentalis (Kennett and Hamai, 1980). The same authors stated that positive reproductive response of a higher percentage of the

species tested on artificial diets suggests that the entirely negative results with the highly predacious mites, P. persimilis and M. occidentalis, were not due to diet composition, but to other causes such as the absence of a phagostimulant. Perhaps, this could also be responsible for the failure of N. idaeus to feed on the artificial diets, and a consequent failure to oviposit on the same. Sabelis (1985) stated that egg production requires much food. Failure, therefore, to feed would consequently result in a failure to reproduce. This was the case with N. idaeus.

On the natural diet, the oviposition rate, fecundity and length of the oviposition period of N. idaeus differs from those reported for many phytoseiids (Collyer, 1956; Putman, 1962; McMurtry and Scriven, 1964; Blommers, 1976, Amano and Chant, 1977, 1978, 1986; De Moraes and McMurtry, 1981). These differences might be specific and also due to varying experimental conditions.

The observed sex ratio in N. idaeus which was largely in favour of females agrees with the general trend observed in phytoseiids (Ballard, 1954; Schulten et al. 1978; Friese and Gilstrap, 1982; Schulten, 1985; Ezulike and Odebiyi, 1985; Dinh et al., 1987; Ochieng et al., 1987).

4.4 Mating Behaviour and Parthenogenesis

The mating behaviour exhibited by N. idaeus characterised by the male climbing on the dorsum of the

female prior to venter-to-venter mating position was observed also in respect of A. fallacis, T. tiliae, A. cucumeris, A. gossypii, A. andersoni, A. finlandicus, P. macropilis and T. pomi (Ballard, 1954; Herbert, 1956; El-Badry and Zaher, 1961; El-Badry and El-Banhawy, 1968; Amano and Chant, 1978, and 1986), but differed from that reported for P. macropilis and P. persimilis (Prasad, 1967; Amano and Chant, 1978). P. macropilis and P. persimilis exhibit the "Phytoseiulus" type of mating behaviour in which both sexes make contact in a face to face position with their palps and first pair of legs after which the male crawl underneath the female in a venter to venter position without first climbing upon the dorsum of the female. These differences could be genetic because Amano and Chant (1978) explained that members of the genus Phytoseiulus generally exhibit rather consistent biological characteristics different from other genera, hence the difference in their mating behaviour from other phytoseiids.

During copulation, the males exhibit periodic jerking movements while the females generally remained stationary (Amano and Chant, 1978). Present observation on N. idaeus agrees with this record, but differs from that of Lee and Davis (1968) in respect of T. occidentalis. They reported that once in copulation the females of T. occidentalis exhibited periodic jerking movements while the male remained stationary. This is unusual. But as it is expected, differences could occur since different species

were involved. Observation on the duration of the copulation period differs from that of the other phytoseiids. While copulation lasted for about 2 1/2 hours in N. idaeus, 14-38 hours was reported for T. tiliae, and 185 hours for A. andersoni (Herbert, 1956; Amano and Chant, 1978). These differences could be specific and due to different experimental conditions.

Parthenogenesis did not occur in N. idaeus. This observation agrees with that reported for phytoseiids in general (Amano and Chant, 1978; Schulten et al. 1978), but differs from the report of Matthysse and Denmark (1981), Wysoki (1985) and Amboga (1986, Pers. Comm.). Amboga worked on the native phytoseiid mite A. teke while N. idaeus is an exotic species. Wysoki (1985) stated that although all phytoseiid species he investigated were haplodiploid, it was doubtful that arrhenotoky occurred in this family.

4.5 Longevity

The results on longevity show that N. idaeus lived significantly longer on the natural diet than on the other diet situations namely artificial liquid-, artificial solid-, a no-food situation and a modified artificial liquid diets. The longer life span on the natural diet shows that the mite fed and derived much benefit from the diet. This observation agrees with that of Shehata and Weismann (1972) for P. persimilis but differs from the

report of Ochieng et al. (1987) for A. teke whose life span on the artificial liquid diet (26 days) was longer than on natural diet (21 days). The non-significant difference in the longevity of the mites on both the artificial diets and the no-food situation indicates that the mites did not feed on the diets. Hence development could not be supported beyond the protonymph stage.

The life span of N. idaeus on the artificial diets differs from that observed in respect of P. persimilis and M. occidentalis (Kennett and Hamai, 1980). The life span on the natural diet also differs from that reported for A. fallacis, T. tiliae, T. umbraticus, P. macropilis, T. occidentalis, A. brazilli, and P. hawaiiensis (Ballard, 1954, Smith and Newsom, 1970; Collyer, 1956; Lee and Davis, 1968; El-Banhawy, 1975; Sanderson and McMurtry, 1984).

Without food, the males of N. idaeus lived significantly longer than the females. This observation differs from that reported in respect of A. bibens (Blommers and Van Arendonk, 1979). The shorter life span of the females might be due to the energy expended during oviposition.

In the present study, the males also lived longer than the mixed sex on the same diet. Though there was no food, mating was observed. The energy expended by both sexes in the exercise might also have been responsible for

the shorter life span observed when both sexes were confined together. Blommers and Van Arendonk (1979) stated that hunger is not detrimental to the willingness of the mites to mate.

Longevity of N. idaeus was the same on the artificial diets under the different confinement conditions. The non-significant difference in the life span might be that the mites were not feeding on the diets. Therefore in an attempt to look, perhaps, for an alternative food source they walked into the water barrier, or the vaseline and talcum powder used for the confinement and died.

The differences in the length of the life span of N. idaeus and that of the other phytoseiids mentioned above might be specific. They might also be due to the different experimental conditions. As stated earlier, the type of prey, temperature, relative humidity and absence of food have been found to influence the length of the life span of the predators (Burrell and McCormick, 1964; Mori and Chant, 1966; Smith and Newsom, 1970; Blommers, 1976; Takafuji and Chant, 1976; De Moraes and McMurtry, 1981; Dinh et al., 1987).

The longer time to extinction on the natural diet shows the superiority of natural diet over the other diet situations. The non-significant difference in the extinction time on the artificial diets and the no-food situation shows that the artificial diets were not suit-

able for the growth and development of N. idaeus. The longer time the males took to go into 40%, 60% and 80% extinction than the females and the mixed sex indicates that the males withstood hunger more than the females. This observation differs from that reported for A. bibens by Blommers and Van Arendonk (1979). These authors reported that the males of A. bibens stand less starvation and have a shorter life span than the females. This difference could be specific.

The food demand of female phytoseiids is higher than that of the males (Sabelis, 1985). This, perhaps, could be the reason that the females could not withstand hunger, hence the shorter time to extinction than the males. Similarly, the short time to extinction shown by the mixed sex could be due to the energy expended during mating (see P. ~~152~~ 143). This, perhaps, could also be responsible for the shorter time shown in days to 40%-, 60% and 80% extinction. However, the mites showed no significant difference in days to 100% extinction.

The non-significant difference in days to 100% extinction shown by the mites with or without confinement on the artificial diets shows the inadequacy of the diets. Since the mites could not feed on the diets, they could not be confined, hence they accidentally walked into the water barrier, vaseline or the talcum powder and died. This observation agrees with that of Muma (1971) who reported that mites exposed to inadequate or survival

foods frequently escaped from feeding and rearing chambers and were lost.

4.6 Feeding Behaviour

It is difficult to compare the feeding of N. idaeus on the natural diet in the present study with that of other phytoseiids. This is because N. idaeus was reared only on one prey the red mites, under constant temperature and relative humidity. However, the preference of the predator to the eggs of its prey is similar to the results reported for T. occidentalis, P. macropilis, A. fallacis, A. umbraticus, P. persimilis, A. bibens and T. floridanus (Chant, 1963, Croft and McMurtry, 1972; Prasad, 1967; Burnett, 1971; Knisley and Swift, 1971; McMurtry and Scriven, 1975; Takafuji and Chant, 1976; Blommers and van Etten, 1975, Blommers, 1976; Tanigoshi and McMurtry, 1977). The observation on the egg preference of N. idaeus also agrees with that of van den Berg (1985) and Dinh et al. (1987) for the same species. But this observation differs from that reported for A. hibisci, Typhlodromus longipilus Nesbitt, T. mcgregori, T. occidentalis, Amblyseius potentillae (Garman) and I. degenerans (McMurtry and Scriven, 1964; Burrell and McCormick, 1964; Croft and Jorgensen, 1969; Croft and McMurtry, 1972; McMurtry and van de Vrie, 1973; Takafuji and Chant, 1976). These differences might be specific. They might also be due to the different prey species offered as food to the predators. This agrees with the

statements by Muma (1971) and Amano and Chant (1986) that members of the phytoseiidae show considerable variation in their feeding habits. Amano and Chant (1986) attributed this difference to the innate characteristic of the species, and also to the relative availability of different food sources in the environment.

The feeding stages of N. idaeus consumed more of the male prey than the females. This might be due to the fact that the male prey are smaller than the females. The female red mites are larger than even the gravid females of N. idaeus. The preference shown for the males to the females of the prey might, therefore, be due to size. The predators probably found it less difficult to overpower the small male prey than the big females. This is similar to the observation reported for A. umbraticus (Knisley and Swift, 1971) whose female prey were so large that they were rarely fed upon. This observation also differs from that reported for P. persimilis (Chant, 1963; Mori and Chant, 1966). Muma (1971) observed that in the genus Neoseiulus Hughes food habits of some species demonstrated considerable intrageneric variation. He attributed this to the varying habitats found among members of the genera, such as ground surface litter and stored food products, to mention a few.

4.7 Cannibalism

Results on cannibalism in N. idaeus under starvation conditions agree with those observed in respect of

A. fallacis (Ballard, 1954, Burnett, 1971) T. caudiglans (Putman, 1962). T. longipilus (Burrell and McCormick, 1964), T. rickeri (McMurtry and Scriven, 1964), M. occidentalis (Laing, 1969) and T. occidentalis (Croft and McMurtry, 1972).

Cases of cannibalism in the presence of the prey were observed in respect of T. cucumeris (El-Badry and Zaher, 1961). However, the observation on cannibalism in N. idaeus disagrees with those of Lee and Davis for T. occidentalis, but agrees with the observations of Croft and McMurtry (1972) in respect of the same species.

Although cannibalistic tendencies of N. idaeus were not tested on other phytoseiid mites, such tendencies abound as was reported by Laing (1969). He observed that M. occidentalis attacked and consumed the eggs and larvae of P. persimilis.

Cannabalism has been described as a means to gain food for development (Sabelis, 1985). The same author also stated that in the struggle at low prey densities natural selection would favour genotypes that code for cannibalism among its juveniles. In this regard, N. idaeus could survive and sustain itself on its own species during periods of prey scarcity in the field, and would return to its normal feeding habits when its prey became abundant again.

4.8 Mortality

N. idaeus was reared for twelve generations and the highest mortality was established at the adult stage. This is significant in view that the adult stage is the most active stage. The males move actively about in search of food and mates, while the females look for a suitable place for oviposition. In this circumstance N. idaeus accidentally moved into the water barrier and got drowned. Most of the deaths were caused in this way.

The deutonymph stage also had a high correlation with the Key-factor (K). This is also understandable in view of the fact that this is the next active stage to the adult.

The larval stage contributed little to the total K. This is not unexpected since the larva is mostly inactive and rarely moves about. It stays most of the time near the place of hatching and goes into a distinct quiescent stage which lasts for about 10 hours. Mortality occurred owing to unsuccessful moulting in a few cases. In some other cases, it was due to escape from the population. So mortality occurred least in the larval-and the egg stages. This observation agrees with that of Sabelis (1985) who stated that juvenile mortality is generally very low when food supply is ample. This, in essence, would mean that searching for food would be minimal and the danger of walking into accidental death

would be rare. A similar observation was also reported by Blommers (1976) that in A. bibens natural mortality seems negligible from birth until far into the reproductive period. In agreement also is the observation by Chant (1963) that winter mortality is severe on adult phytoseiids. This is expected since phytoseiids overwinter as adult females according to the above author.

The successful rearing of N. idaeus for 12 generations is unique and differs from the report of Collyer (1956) that the adult females of T. tiliae collected in the first week of may 1953 completed 4 generations before the development of overwintering females in mid-September of the same year. It also differs from the observation of Lee and Davis (1968) that T. occidentalis passed, at least, through 10 generations in a season. These differences might be specific, and due probably to the differences in the experimental conditions.

Mortality at the egg stage was caused by egg shrivelling or failure of the egg to hatch. Sabelis (1985) stated that high humidity and immersion in water are deterimental to egg hatching. He stated further that even after a few hours immersion in water, the eggs fail to hatch. The same author explained that larvae and nymphs are less sensitive to immersion, but they may die because after drying their legs, they become stuck to their body or to the substrate. De Moraes and McMurtry (1981) stated that premature mortality might be associated

with the presence of precipitates, probably of guanine frequently observed through the transparent cuticle as large white masses in the diverticula. The legs on the side of the body where the precipitate occurred could not move normally at times, and the female apparently died prematurely. The observed mortality in the egg stage and the immature stages of N. idaeus is similar to the observation of Blommers and Van Etten (1975) for A. bibens but differs from that reported in respect of the same species by Dinh et al. (1987) in which no mortality was observed in the egg stage and the immature stages. This difference might be due to the difference in the experimental conditions.

4.9 Life Table

Birch (1948) defined the intrinsic rate of increase as the rate per head under specified physical conditions in an unlimited environment where the effects of increasing density do not need to be considered, and where there are no mortality factors other than physiological ones. In the present study the intrinsic rate of increase of N. idaeus was quite high while the generation time was short. According to Birch (1948), a longer developmental time would operate to reduce the value of rm. In this study, the shorter developmental time (generation time) and the high female bias in the sex ratio might have been responsible for the high rm observed. Similarly the finite rate of increase was also high. These values are

different from those reported by Laing (1968, 1969) for P. persimilis and M. occidentalis, Blommers (1976) for A. bibens, Badii and McMurtry (1984) for P. longipes, and Dinh et al. (1987) in respect of N. idaeus. Southwood (1984) stated that values of Ro in excess of one imply an increasing population. The observations made in the present study agree with this finding, but differ from those of the species reported above. These differences might be specific and due probably to varying experimental conditions.

SUMMARY

1. *N. idaeus* passed through the five developmental stages common to phytoseiids namely, egg, larva, protonymph, deutonymph, and the adult stage. These stages were completed on the natural diet. On the artificial diets, the mite did not develop beyond the protonymph stage. On both the natural and the artificial diets, there was a distinct quiescent stage for each stage of development. On the natural diet, the developmental period (egg-to-egg) was quite short (5.83 days). The males developed a little faster than the females.

2. There are two sexes. The females are bigger than the males. The larva has three pairs of legs while the other stages have four.

3. The fecundity rate was high, but the overall mean was low because of mortality during the reproductive period. Females required mating before oviposition, and repeated mating was necessary for the females to lay their full complement of eggs. The sex ratio was strongly female biased (3-4 females to 1 male).

4. The adult males and females lived significantly longer on the natural diet than on the artificial diets. There was no significant difference in the length of the life span on the artificial diets and the no-food situation.

5. The males lived significantly longer without food than the females or the mixed sex.

6. The length of the life span on the artificial diets was the same when confined with vaseline, Talcum powder or without any confinement.

7. The mites also took a longer time to go into extinction on the natural diet than on other diet situations. There was no significant difference in the extinction time on the rest of the diets.

8. The males took a longer time to go into 40%, 60% and 80% extinction without food than the females or the mixed sex. There was no significant difference between the females and the mixed sex in days to these percentage extinction. However, there was no significant difference between the sexes in days to 100% extinction. Similarly the mites showed no significant difference in days to 100% extinction with or without confinement.

9. N. idaeus showed specific preference for the eggs of its prey (red mite). There was no difference in prey stage preference between the protonymphs and the deutonymphs, and between the adult males and females. The larval stage did not feed on any of the prey stages.

10. The highest mortality was recorded in the adult stage. The intrinsic rate of increase (rm) and the finite rate of increase Lambda (λ) were quite high. The

generation time (T) was very short. The population multiplied 7-12 times in a generation time of about 3 days.

11. From this study, N. idaeus seems to be a promising candidate for the biological control of the green spider mite. The high intrinsic rate of increase (rm) and the short generation time (T) of the predator are advantageous over its prey whose generation time is much longer than that of the predator. This shows that the predator has the potential for a rapid build up in the population to cope with the increase in prey numbers.

12. The cannibalistic tendencies of the predator in the absence of its prey shows that in periods of prey scarcity in the field, N. idaeus could sustain itself temporarily on its own species till the prey becomes abundant. It is, therefore, not likely that it may go into extinction before the resurgence of the prey.

13. The longer life span of the males than the females without food indicates that there would always be males in the population to fertilize the females since arrhenotoky was not observed in the species under study.

14. Non-feeding in the larval stage would be advantageous as it may reduce intraspecific competition and allow a more equitable sharing of the same habitat among the feeding members of the same species.

15. Since the artificial diet (ICD 286) was able to sustain the predator up to the protonymph stage it is possible that it could sustain it on transit to the recipient country before it can be reared on a natural host for mass releases.

16. The high female bias in the sex ratio (3.53 to 1 m) indicates that the predator will always increase in numbers for the perpetuation of its species.

17. Within the limits of this study, and with the attributes found in the predator, I recommend N. idaeus as a possible candidate for the biological control of the green spider mite which is a serious pest of cassava. The control of this pest will increase production of cassava which is a popular staple food for many African families.

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Appendix 1 Egg hatching on Natural -, Artificial Liquid -, and Artificial Solid Diets.
(Time in hrs : Mean±SE)

	Test 1			Test 2			Test 3			Test 4			Test 5			Test 6		
	ND	ALD	ASD	ND	ALD	ASD	ND	ALD	ASD	ND	ALD	ASD	ND	ALD	ASD	ND	ALD	ASD
1	40	34	36	43	37.5	40	42	36	38	39	34	39	40	42	38	38.5	36	36
2	40	34	38	42	37.5	40	39	35	38	36	34	37.5	41	36	38	37.5	36	37
3	40	40	37	40	37.5	38	38	43	35.5	36	34	39	38.5	35	40	37	34	37.5
4	42	34	34	39	37.5	39	39	39	37	42	36	41	39	40	41	39	35.5	38
5	38	34	35	39	37	39	39	39	39	41	40	36	39	34	38	39	40	40.5
6	42	34	35.5	39	37	38	39	35	39	40	34	38	40	34	39	41	39	41
7	39	34	36	39	35	41	40	35	37.5	38.5	34	38	37	37	38.5	40	37.5	38
8	38	36	37	40	34	39	41	37	40	39	34	37.5	41	34	37	41	36	40
9	38	34	38	41	34	36	40	41	41	39	34	39	39	36	40	39	34	41
10	40	36	37.5	42	36	37.5	38	37	38.5	40	34	40	39	37.5	39	42	41	41
Mean	39.7	35.0	36.4	40.4	36.3	38.75	39.5	37.7	38.35	39.05	34.8	38.5	39.35	36.55	38.85	39.4	36.9	39.0
SE	0.47	0.61	0.42	0.48	0.46	0.45	0.40	0.87	0.49	0.61	0.61	0.45	0.38	0.85	0.38	0.50	0.76	0.60

ND = Natural Diet; ALD = Artificial Liquid Diet; ASD = Artificial Solid Diet

Appendix 2 Larval development on Natural -, Artificial Liquid -, and Artificial Solid Diets.
(Time in hrs : Mean±SE)

	Test 1			Test 2			Test 3			Test 4			Test 5			Test 6		
	ND	ALD	ASD	ND	ALD	ASD	ND	ALD	ASD	ND	ALD	ASD	ND	ALD	ASD	ND	ALD	ASD
1	12	8	14	14	10	13	14	12	13.5	13	12	12	12.5	11.5	12	12	13.5	14
2	14	10	14	14	12	12	14	12.5	12.5	16	12	11	14	12	12	12	13.5	14
3	12	12	12	16	13	11	14	12	14	11	10	11	14	12	14	13	14	12
4	12	10	11.5	14	12	11	14	14	14	12	14	11	14	13.5	13	12.5	14	12
5	14	12	12	12	12	12	16	14	14	13	10	12	16	11	11	13	14	11.5
6	14	14	11.5	12	12	13	12	12	12	10	12	12	13.5	12	12	14	12	12
7	14	14.5	12	12	13	11	12	12	12	12	16	12.5	12	14	13.5	6	12	12
8	14	11	12	12.5	11	11	16	14	14	12.5	13.5	11	12	14.5	12	12.5	12	12.5
9	12	11	12.5	12	10	12	14	8	12.5	14	14	11	14	13.5	14	10	11.5	12.5
10	10	8	12.5	14	10	12	12	14	12	13	14	12	12.5	12	14	11	13.5	12
Mean	12.8	11.05	12.4	13.25	11.5	11.8	13.8	12.45	13.05	12.65	12.75	11.55	13.45	12.6	12.75	11.6	13.0	12.45
SE	0.44	0.69	0.29	0.43	0.37	0.25	0.47	0.58	0.29	0.52	0.60	0.19	0.39	0.37	0.34	0.71	0.32	0.27

ND = Natural Diet; ALD = Artificial Liquid Diet; ASD = Artificial Solid Diet.

Appendix 3. Protonymph development on Natural-, Artificial Liquid-, and Artificial Solid Diets.
(Time in hrs. : Mean±SE)

	Test 1			Test 2			Test 3			Test 4			Test 5			Test 6		
	ND	ALD	ASD	ND	ALD	ASD	ND	ALD	ASD	ND	ALD	ASD	ND	ALD	ASD	ND	ALD	ASD
1	24	0	0	24	0	0	26	0	0	26	0	0	24	0	0	26	0	0
2	24	0	0	24	0	0	26	0	0	26	0	0	24	0	0	26	0	0
3	24	0	0	26	0	0	26	0	0	26	0	0	26	0	0	24	0	0
4	22	0	0	24	0	0	26	0	0	24	0	0	24	0	0	24	0	0
5	24	0	0	24	0	0	26	0	0	25	0	0	25	0	0	23	0	0
6	24	0	0	26	0	0	24	0	0	27	0	0	27	0	0	25	0	0
7	24	0	0	26	0	0	24	0	0	28	0	0	26.5	0	0	32	0	0
8	24	0	0	14	0	0	26	0	0	26.5	0	0	24	0	0	26.5	0	0
9	26	0	0	26	0	0	26	0	0	24	0	0	26	0	0	27.5	0	0
10	24	0	0	24	0	0	28	0	0	24	0	0	26	0	0	26	0	0
Mean	24.0	0.0	0.0	23.8	0.0	0.0	25.8	0.0	0.0	25.65	0.0	0.0	25.25	0.0	0.0	26.0	0.0	0.0
SE	0.30	0.0	0.00	1.13	0.0	0.0	0.36	0.0	0.0	0.43	0.0	0.0	0.37	0.0	0.0	0.79	0.0	0.0

ND = Natural Diet; ALD = Artificial Liquid Diet; ASD = Artificial Solid Diet; 0 = No development.

Appendix 4 Development of Deutonymph to the adult stage on Natural -, Artificial liquid -, and artificial Solid Diets. (Time in hrs : Mean±SE)

	Test 1			Test 2			Test 3			Test 4			Test 5			Test 6		
	ND	ALD	ASD	ND	ALD	ASD	ND	ALD	ASD	ND	ALD	ASD	ND	ALD	ASD	ND	ALD	ASD
1	24	0	0	26	0	0	22	0	0	24	0	0	23	0	0	25.5	0	0
2	24	0	0	26	0	0	22	0	0	24	0	0	24	0	0	25	0	0
3	26	0	0	24	0	0	24.5	0	0	24	0	0	22	0	0	26	0	0
4	26	0	0	24	0	0	22	0	0	30	0	0	25	0	0	26	0	0
5	24	0	0	27.5	0	0	22	0	0	25	0	0	25.5	0	0	22	0	0
6	24	0	0	24	0	0	24	0	0	25.5	0	0	24	0	0	24	0	0
7	24	0	0	22	0	0	24	0	0	25	0	0	24	0	0	24	0	0
8	24	0	0	28	0	0	24	0	0	23	0	0	26	0	0	24	0	0
9	22	0	0	24	0	0	26	0	0	28	0	0	24	0	0	26	0	0
10	24	0	0	24	0	0	22	0	0	24	0	0	23.5	0	0	24	0	0
Mean	24.2	0.00	0.00	24.95	0.00	0.00	23.25	0.00	0.00	25.5	0.00	0.00	24.1	0.00	0.00	24.65	0.00	0.00
SE	0.36	0.00	0.00	0.59	0.00	0.00	0.45	0.00	0.00	0.68	0.00	0.00	0.37	0.00	0.00	0.41	0.00	0.00

ND = Natural Diet; ALD = Artificial Liquid Diet; ASD = Artificial Solid Diet; 0 = No development.

Appendix 5. Preoviposition Period (Adult - Egg) on the three diet forms. (Time in hrs.)

	TEST 1			TEST 2		
	ND	ALD	ASD	ND	ALD	ASD
1	40	0	0	46	0	0
2	40	0	0	37.5	0	0
3	36	0	0	36	0	0
4	37	0	0	36	0	0
5	36	0	0	37.5	0	0
6	38.5	0	0	38.5	0	0
7	37	0	0	40	0	0
8	37.5	0	0	36	0	0
9	36	0	0	36	0	0
10	41	0	0	38	0	0
Mean	37.9	0.00	0.00	38.15	0.00	0.00
SE(±)	0.59	0.00	0.00	0.97	0.00	0.00

ND = Natural Diet

ALD = Artificial Liquid Diet

ASD = Artificial Solid Diet

0 = No development.

Appendix 6. Measurements of the Various Life Stages

	Egg		Larvae		Protonymph	
	Length	Width	Length	Width	Length	Width
1	0.18	0.15	242.05	164.8	257.5	190.55
2	0.18	0.15	236.9	190.55	278.1	190.55
3	0.18	0.15	231.75	169.95	242.05	175.1
4	0.18	0.15	231.75	154.5	278.1	185.4
5	0.18	0.14	242.05	185.4	272.95	169.95
6	0.18	0.14	226.6	169.95	221.45	157.075
7	0.18	0.14	236.9	175.1	283.25	190.55
8	0.18	0.14	226.6	149.35	247.2	180.25
9	0.18	0.14	236.9	164.8	234.325	146.775
10	0.18	0.14	231.75	164.8	236.9	159.65
11	0.18	0.14	229.175	144.2	296.125	218.875
12	0.18	0.14	231.75	149.35	285.825	200.85
13	0.18	0.14	226.6	139.05	236.9	169.95
14	0.18	0.14	224.025	149.35	298.7	195.7
15	0.18	0.14	236.9	182.825	293.55	190.55
16	0.18	0.15	221.45	139.05	242.05	144.2
17	0.18	0.14	252.35	198.275	247.2	144.2
18	0.18	0.14	218.875	167.375	262.65	169.95
19	0.18	0.14	221.45	169.95	254.925	162.225
20	0.18	0.15	221.15	149.35	231.75	144.2
Mean	0.18	0.14	230.8488	163.90	260.075	174.3275
SE	0.00	0.00	2.099	3.81	5.375	4.74

Size (μm) (Mean ± SE) (For the active stages)

Size of Egg = mm (x ± SE) = 0.18 ± 0.00 x 0.14 ± 0.00mm
Larvae = 230.85 ± 2.1 x 163.90 ± 3.81 μm
Protonymph = 260.08 ± 5.38 x 174.33 ± 4.74
Deutonymph = 356.12 ± 16.14 x 232.14 ± 9.68
Adult female = 469.68 ± 12.59 x 305.91 ± 12.42
Adult Male = 314.92 ± 3.66 x 208.70 ± 5.05

Appendix 6 (Cont'd)

	Deutonymph		Adult female		Adult male	
	Length	Width	Length	Width	Length	Width
1	293.55	190.55	463.5	298.7	321.875	206
2	247.2	175.1	422.3	303.85	309	206
3	293.55	203.425	515	334.75	332.175	236.9
4	360.5	206	309	206	293.55	185.4
5	288.4	203.425	417.15	221.45	306.25	195.7
6	283.25	190.55	515	334.75	360.5	257.5
7	252.35	193.125	540.75	388.825	344.75	242.05
8	530.45	350.2	545.9	355.35	334.75	242.05
9	422.3	283.25	435.175	262.65	309	193.125
10	365.65	244.625	435.175	221.45	293.55	195.7
11	381.1	247.2	435.175	221.45	311.575	216.3
12	391.4	262.65	491.825	352.775	309	200.85
13	381.1	247.2	468.65	329.6	298.7	203.425
14	365.65	231.75	473.8	345.05	306.425	200.85
15	293.55	206	458.35	293.55	303.85	169.95
16	473.8	309	442.9	298.7	319.3	226.6
17	360.5	221.45	561.35	391.4	314.15	206
18	345.05	221.45	489.25	334.75	303.85	180.25
19.	401.7	234.325	478.95	283.25	309	193.125
20	391.4	221.45	494.4	339.9	327.025	216.3
Mean	356.12	232.136	469.68	305.91	314.92	208.70
SE(±)	16.14	9.68	12.59	12.42	3.66	5.05

Appendix 7. Longevity of N. idaeus on five_food Situations: (Time in days).

	Natural	Artificial Liquid	Artificial Solid	No-food Situation	Modified Art. Liq. Diet.
1	17.4	2.2	4.4	1.2	3.0
2	3.0	3.0	3.0	1.4	2.0
3	34.4	1.8	7.4	1.2	2.4
4	4.2	2.0	3.8	1.4	1.4
5	12.2	2.4	3.8	1.2	2.8
6	9.4	2.2	4.4	1.0	
7	11.4	3.0	4.2	1.2	
8	13.2	4.0	1.6	1.6	
9	18.4	3.2	2.8	1.2	
10	15.2	2.2	4.6	1.4	
Mean	13.88	2.60	4.0	1.28	2.32
SE(±)	2.78	0.21	0.48	0.05	0.29

Appendix 8. Longevity of Male, Female, and Mixed Sex (F + M) on a No-Food Situation. (Time in days).

	Females	Males	Mixed Sex (F + M)
1	1.0	1.8	1.2
2	2.2	1.4	1.4
3	1.8	2.0	1.2
4	1.4	2.4	1.4
5	1.0	1.8	1.2
6	2.0	2.4	1.0
7	1.4	2.2	1.2
8	1.2	1.6	1.6
9	1.6	1.8	1.2
10	1.8	2.2	1.4
Mean	1.54	1.96	1.28
SE(±)	0.13	0.11	0.05

Appendix 9. Longevity of N. idaeus on Two Artificial Diets when confined with Vaseline, Talcum Powder and with No-confinement.
(Time in days)

	Artificial Liquid Diet			Artificial Solid Diet		
	Vaseline	Talcum Powder	No Confinement	Vaseline	Talcum Powder	No Confinement
1	2.2	2.75	3.25	4.4	2.5	1.0
2	3.0	1.5	1.25	3.0	2.5	2.75
3	1.8	2.0	3.0	7.4	2.75	2.0
4	2.0	1.5	3.0	3.8	3.75	3.25
5	2.4	2.5	1.75	3.8	2.25	1.25
6	2.2	2.25	2.5	4.4	2.5	1.75
7	3.0	2.0	3.5	4.2	2.5	2.75
8	4.0	3.25	2.0	1.6	2.25	3.25
9	3.2	1.5	3.25	2.8	2.75	3.5
10	2.0	1.5	2.75	4.6	2.75	1.0
Mean	2.6	2.075	2.625	4.0	2.65	2.25
SE(±)	0.22	0.19	0.23	0.48	0.14	0.31

Appendix 10. Days to 100% Extinction on Five-Food Situations.

	Natural Diet	Artificial Liquid	Artificial Solid	No-Food Situation	Modified Art. Liq. Diet
1	24	4	10	2	4
2	9	6	7	3	4
3	52	2	11	2	7
4	8	3	9	3	3
5	18	4	9	2	5
6	15	5	9	1	
7	15	6	10	2	
8	23	7	2	3	
9	29	5	6	2	
10	27	4	10	2	
Mean	22.0	4.6	8.3	2.2	4.6
SE(±)	4.02	0.48	0.84	0.2	0.67

Appendix 11. Days To 80% Extinction on Five - Food Situations.

	Natural Diet	Artificial Liquid	Artificial Solid	No-Food Situation	Modified Art. Liq. Diet.
1	22	2	3	1	4
2	2	3	3	1	2
3	49	2	10	1	2
4	7	2	4	1	1
5	17	3	4	1	4
6	15	2	5	1	
7	15	3	6	1	
8	18	7	2	2	
9	24	4	3	1	
10	22	2	4	2	
Mean	19.1	3.0	4.4	1.2	2.6
SE(±)	3.96	0.49	0.72	0.13	0.60

Appendix 12. Days To 60% Extinction on Five - Food Situations.

	Natural Diet	Artificial Liquid	Artificial Solid	No - Food Situation	Modified Art. Liq. Diet.
1	15	2	3	1	3
2	2	2	3	1	2
3	36	2	9	1	1
4	4	2	3	1	1
5	14	2	2	1	2
6	13	2	4	1	
7	10	3	3	1	
8	18	3	2	1	
9	19	3	3	1	
10	22	2	4	1	
Mean	15.3	2.3	3.6	1.0	1.8
SE(±)	3.04	0.15	0.64	0.00	0.37

Appendix 13. Days To 40% Extinction on Five - Food Situations.

	Natural Diet	Artificial Liquid	Artificial Solid	No-Food Situation	Modified Art. Liq. Diet.
1	14	2	3	1	2
2	1	2	1	1	1
3	29	2	5	1	1
4	1	2	2	1	1
5	9	2	2	1	2
6	2	1	3	1	
7	10	2	1	1	
8	5	2	1	1	
9	15	3	1	1	
10	3	2	3	1	
Mean	8.9	2.0	2.2	1.0	1.4
SE(±)	2.77	0.15	0.42	0	0.24

Appendix 14. Days To 20% Extinction on Five - Food Situations.

	Natural Diet	Artificial Liquid	Artificial Solid	No-food Situation	Modified Artif. Liquid Diet.
1	12	1	3	1	2
2	1	2	1	1	1
3	6	1	2	1	1
4	1	1	1	1	1
5	3	1	2	1	1
6	2	1	1	1	
7	7	1	1	1	
8	2	1	1	1	
9	5	1	1	1	
10	2	1	2	1	
Mean	4.1	1.1	1.5	1.0	1.2
SE(±)	1.1	0.1	0.22	0.00	0.20

Appendix 15. Days to Percent Extinction of Males, Females and Mixed Sex of *N. idaeus* on a No-Food Situation.

	100%			80%			60%			40%			20%		
	F	M	MX	F	M	MX	F	M	MX	F	M	MX	F	M	MX
1	1	3	2	1	2	1	1	2	1	1	1	1	1	1	1
2	3	2	3	3	2	1	2	1	1	2	1	1	1	1	1
3	4	3	2	2	3	1	1	2	1	1	1	1	1	1	1
4	3	3	3	1	3	1	1	3	1	1	2	1	1	1	1
5	1	3	2	1	2	1	1	2	1	1	1	1	1	1	1
6	4	3	1	2	3	1	2	3	1	1	2	1	1	1	1
7	2	3	2	2	3	1	1	2	1	1	2	1	1	1	1
8	2	2	3	1	2	2	1	2	1	1	1	1	1	1	1
9	3	3	2	2	2	1	1	2	1	1	1	1	1	1	1
10	3	4	2	2	2	2	2	2	1	1	2	1	1	1	1
Mean	2.6	2.9	2.2	1.7	2.4	1.2	1.3	2.1	1.0	1.1	1.4	1.0	1.0	1.0	1.0
SE(±)	0.34	0.18	0.2	0.21	0.16	0.13	0.15	0.18	0.00	0.10	0.16	0.00	0.00	0.00	0.00

F = Females; M = Males= MX = Mixed Sex

Appendix 16. Days to 100% Extinction of N. idaeus on Artificial Liquid - and Artificial Solid Diets when confined with Vaseline, Talcum Powder, and Without Confinement.

	Artificial Liquid Diet			Artificial Solid Diet.		
	Vaseline	Talcum Powder	No. Confinement	Vaseline	Talcum Powder	No. Confinement
1	4	6	9	10	5	1
2	6	3	2	7	4	7
3	2	5	6	11	5	5
4	3	3	6	9	5	10
5	4	5	3	9	3	2
6	5	5	3	9	5	3
7	6	3	6	10	4	7
8	7	7	3	2	5	10
9	5	2	6	6	4	11
10	4	3	5	10	5	1
Mean	4.6	4.2	4.9	8.3	4.5	5.7
SE(±)	0.48	0.51	0.67	0.84	0.22	1.22