1. INTRODUCTION

Onion (*Allium cepa*) is a popular vegetable grown for its pungent bulb and flavorful leaves. The earliest onion cultivation is believed to have started at the age of the Mediterranean as long ago as 5,000 years (Hanley and Fanwick, 1985). Onions were first grown in Iran and Pakistan but others believe that it originated in central Asia (Griffith *et al.,* 1994). In addition to its flavor and nutritional importance, many pharmacological benefits have been attributed to this vegetable throughout the centuries. The plant or the plant parts have been prescribed for a variety of ills including coughs, colds, stomach ailments, cancer and heart problem (Griffith *et al.,* 1994).

Onion is widely grown throughout the world. The bulb is composed of concentric, fleshy, enlarged leaf bases or scales. The outer leaf bases lose moisture and become scaly and the inner leaves generally thicken as bulbs develop. The green leaves above the bulb are hallow and arise sequentially from the meristem at the innermost point at the base of the bulb. The stem is very small and inconspicuous during vegetative growth. The onion root system is fibrous, spreading just beneath the soil surface to a distance of 30 to 46cm. There are few laterals and total root growth is spares and not especially aggressive (Suman, 1980).

Shallots (*Allium cepa aggregatum)* are the traditional crops in Ethiopia. A survey made in 2005 estimated the total area under onions and shallot cultivation in Ethiopia to be about 10,000 ha with the total production of about 75,500 tones (Aklilu, 1997). Currently, the crops are produced in different parts of the country for local consumption and for export to European market. Varieties produced in Ethiopia are more preferable among producers because of advantages of high yield potential, and ease of propagation by seed and bulb (Melkassa Agricultural Research Center, 2001).

The optimum altitudinal range favorable for onion cultivation under Ethiopian conditions is between 700 and 1800m a.s.l.

Onion is susceptible to a number of diseases and few insect pests that can seriously determine onion production. Among this, onion thrips, *T. tabacci* Lindeman, is a key pest of onion. It is also important on several other crops in most parts of the world (Lewis, 1997).

Several control measures have been employed to control onion thrips. Among these integrated organic pest control methods which emphasizes mainly on the preventive aspect than treating of pest problems after they occurred have been adopted for the control of *T. tabaci* (Bowman, 1997). This is part of an Integrated Pest Management program (IPM) with little or no chemical application, which is recently introduced as Biointensive Integrated Pest Management program (BIPM) (Benbrook, 1996). It is production management system that promotes and enhances agro-ecosystem health, including biodiversity, biological cycles and soil biological activity.

Therefore, this study aimed at investigating the impact of manure application and host plant spacing on the infestation level and damage of *T. tabaci* on onion.

Objectives of the study

General objective

To study the infestation level and damage of onion thrips with different plant spacing and period of manure application.

Specific objectives

1. To determine the appropriate period of manure application and plant spacing for effective control of *T. tabaci* on onion.

2. To assess the impact of plant spacing for integrated onion thrips control.

3. To determine onion yield loss due to infestation and damage by *T. tabaci* under this system.

2. REVIEW OF THE LITERATURE

2.1 Taxonomic status and geographical distribution of *Thrips tabaci* Lindeman.

2.1.1 Taxonomic status

Thrips are generally considered to constitute a single order of insects, the Thysanoptera. Adults and larvae of the two suborders, Terebratia and Tubulifera, share one unique structural attribute in that only the left mandibles is fully developed, and the right one is resorbed by the embryo (Hemmings, 1978).

Thysanoptera means "fringed wings" as both pairs of wings in adults bear a marginal fringe of long setae. Although wings with fringes occur in several other groups of small insects, adults of many thrips species are wingless. The common name, thrips is the Greek word for "Wood worm" derived from observations by early naturalists that many species are found on dead branches.

Thrips tabaci and most crop damaging thysanopterans belong to the family Thripidae in the suborder Terebratia (Loomans *et al.,* 1995). It was first described by De Gear in 1744, under the name *Physapus*, which Linneaus placed in genus *Thrips* in 1758 (Lewis, 1997); this group was elevated to the rank of an order by Halidey; in 1936 (Lewis, 1997). The order presently includes over 5,000 species.

The family Thripidae includes about 1700 species in 260 genera (Mound and Kibby, 1998). Within the subfamily Thripinae, the genus *Frenkiniella* Karry and *Thrips* Linnaeus are the most commonly recorded on onions (Bender and Morrison, 1989; Stiller, 2001). The genus *Thrips* Linnaeus has been described

containing 275 species listed worldwide (Mound and Kibby, 1998). About 11 species of the genus have been repotted in Africa; but the most common in the onions agro-ecosystems were reported to be *T. tabaci* Lindeman, Gladlolus thrips and *T. simplex* (Stiller, 2001).

2.1.2 Geographical Distribution

Thrips tabaci Lindeman has been reported as the most common and widespread phytophagous thrips species (Lindeman, 1889; Palmer, 1990; Loomas *et al.*, 1995; Lewis, 1997; Mound and kibby, 1998). The origin of the genus *Thrips*, to which *T. tabaci* belongs, is probably from the central palaerctic region, more specifically the Middle East and Black sea area from where its preferred onion host plant, *Allium cepa* is derived (Lindeman, 1889; Mound, 1997). Presently, the onion thrips is a cosmopolitan species occurring in tropical, subtropical and temperate onion growing regions between sea level and 2000m.a.s.l worldwide (Lewis 1973; Chang 1991). In most countries *T. tabaci* accounts over 50% to 80% of the thrips present in onions, garlic and leaks (Bender and Morrison, 1989; Weiss and Beshear, 1987).

Thrips tabaci is also reported in Africa (Le Pelley, 1959), but information on its geographical distribution, infestation patterns and pest status are scarce. In East Africa, *T. tabaci* was first observed by Wilkinson in 1937 on pyrethrum, *chrysanthemum cineraiifolium* in Kenya, where it was causing damage to inflorescences (KARI/ODA, 1994). The pest status on pyrethrum was also studied by Bullock (1957). Later, thrips was recorded on onions and leeks (Allium *porrum*) in Kenya and Tanzania (Le pelley, 1959). A recent survey in onion growing areas in Kenya showed that *T. tabaci* was the major pest. It is also the only major insect pest of onion crops recorded in Ethiopia (Crowe and Shitaye, 1977; Institute of Agricultural Research, 1980; Tsedeke Abate 1986).

2.2 Biology and Ecology of *Thrips tabaci* L.

2.2.1 Biology

Thrips tabaci are relatively small, slender and fast moving insects. The body color ranges from pale yellow to dark brown. The male of the species is wingless and is rarely found. The females have four very slender, unbanded and dirty grey wings. The wings are unique among insects because they have a single longitudinal vein in which there are several hairs connected perpendicular to the vein and appear as fringe with hairs. When at rest, the wings are laid over the abdomen and extended slightly pass it (Anon, 1992).

Thrips have characteristic life cycles that consist of egg, two active larval stages, an inactive and non-feeding prepupa and pupal stages, and adult stage (Moritz, 1997)(Fig. 1). Eggs are deposited in a host plant tissue, both larval stages search for shelter to pupate, mostly in the soil under leaf litter or between debris (Binns *et al.,* 1982: de Kogel, 1997).

Thrips tabaci is parthenogentic over much of its geographical range, since sex ratio patterns are strongly female biased in most field populations. They exhibit both arrhenotokous and thelytokous population. In arrhenotokous population, haploid males are produced only by unfertilized eggs and diploid females, whereas, fertilized females produce female offspring from fertilized eggs (Moritz, 1997). Thelytokous population occurs when females are diploid and are produced by obligate parthenogenesis by unfertilized females. Thrips, which are particularly found on onion, leek and garlic are predominantly thelytokous (Vierbergen, 1990; Ester and Vierbergen, 1997; Franco *et al.*, 1998). Although sex ratio patterns vary in time and place, males are rather rare in most parts of the world or completely absent (Kendall and Capinera, 1990). On the other hand, males are very common on tobacco. While 40-50%

males found on onion in late seasons coinciding with a high relative amount (80%) larvae in the population.

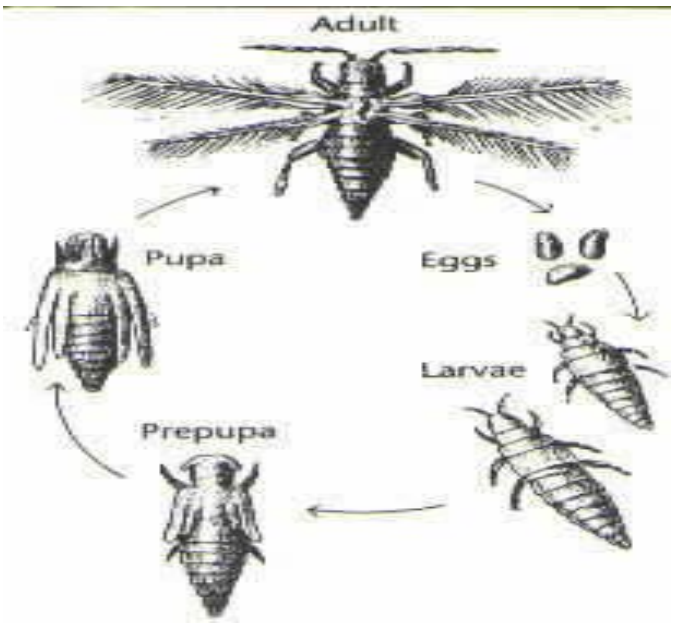

Figure 1. Life cycle of *Thrips tabaci* Lindeman (Lewis, 1973)

Developmental times and life history traits, like pre-oviposition period, fecundity, longevity and reproductive potential are largely governed by temperature, host plant species, and host plant cultivars and to some extent by photoperiod (Tommasini and Nicoli, 1995; Brodsgaard, 1990).

Most thrips complete their life cycles from egg to adult stage in two to three weeks. The duration varies with the host and with abiotic factors such as temperatures and humidity. Because of their small size, this pest species like other thrips cannot readily be identified even with a hand lens (Bocak, 1996).

Females have a saw like ovipositor that helps to make an incision in plant tissue for egg laying. Egg are placed singly just under epidermis of succulent leaf, flower, stem or bulb tissues. Eggs are elliptical, about 0.2mm long. They are whitish at oviposition and change to an orange tint as development continues. Larvae are whitish to yellowish in color. The first instar larvae are

white, about 0.35mm long and the second instar larvae are yellowish, about 0.7 to 0.9 mm long. These two larval stages and the adult are the only damaging stages in the pest life cycle. Thrips pupae appear as intermediate between the immature and adults. There are two non-feeding stages that occur primarily in the soil base of plant neck. They are similar to the second instar larvae in color and shape, except for having small winged pads (Andaro and Shelton, 1983).

Onion thrips have two to ten generations depending on the temperature. The average length of development is 6 to 8 days for eggs, 19 to 14 days for larvae, 5 to 9 days for prepupae and pupae, and about 20 days for generation. It may take as long as 35days for a generation if the temperature is at 15 ^{0}c and the life cycle can be shortened 10 to11 days at 30^{0}c. The lower developmental threshold is about 11.5^{0}c and using this threshold, as a base development required 191-dgree days. Adults reproduce parthenogentically throughout the season, rarely reproduce sexually, and resulting that most adult in the field are females. The average adult life is around 32 days and pre-oviposition and post-oviposition periods are 6.1, 22.5 and 3.9 days respectively. The average number of eggs laid by an unmated female is 37.4(20to 200) (Davis *et al.*, 1995). The females live much longer than the males and hence an overlapping of generations occurs.

2.2.2 Ecology of *Thrips tabaci* L.

The various components in mode of life to species like *T. tabaci* give opportunities to colonies new habitats (Mound and Teulon, 1995). First this species have important features of an opportunistic mode of life which can make them become pest once they have arrived in a new habitat, such as a high reproductive capacity (parthenogentic mode of reproduction), pesticide resistance, a wide host plant and habitat range (Mound and Teulon, 1995), second their preference for young host plant tissue, together with their hidden life style (inside plant tissue and soil), which protect them during short period of travel in horticultural products like vegetables and flowers and bedding plants, allow them to cover long distances without problems.

The population dynamics of *T. tabaci* is controlled by abiotic and biotic factors including trophic influences of the host plant. Seasonal population peaks of *T. tabaci* are governed by temperature and rainfall. Temperature dependent development on *T. tabaci* has been the subject of many studies. Van Rijn *et al.,* (1995) used, the Logan *et al.*, (1976) model to represent the development rate of immature *T. tabaci* life stages within the temperature range allowing development. Domiciano *et al.,* (1993) and Hamdy and Salem (1994), observed that the rate of development of *T. tabaci* was positively affected by increased temperature and negatively by increased relative humidity. At high temperatures, female *T. tabaci* were reported to lay most of their eggs and lived longest (Jimenez and Roscandio, 1996). The authors recorded minimum development thresholds of 10.4^0c and 11.2^0c in onion and garlic, respectively. Temperature has also been found to affect the mortality and fecundity of *T. tabaci* as quantified by Van Rijn *et al.*, (1995), while Murai (2000) has characterized temperature effects on development and reproduction of these species. In combination with other abiotic factors it is assumed to largely control population development. Domiciano *et al.*, (1993), while studying the

association of population fluctuations of thrips on onion with climatic elements, reported that typical conditions that favor rapid increase in thrips population occurred within temperature range of 20-29^{0}c,in the absence of rainfall.

Rainfall combined with cool temperature, has also been shown to be detrimental to thrips in onion, where as, warmer and drier conditions led to increased densities (Harding, 1961). Heavy rainfall is reported to wash thrips off plants, causing sudden sharp declines in their population density (Harris *et al.,* 1936). In a similar way, irrigation at the soil surface has been reported to reduce the population more than rain probably as a result of soil caking kills thrips present in the soil (Ananthakrishnan, 1993; Krik, 1984).

This inverse relationship was higher under dry conditions and hence hypothesized that high soil moisture enhanced entopathogenic fungal growth, resulting in great degree of thrips pupal infestation, which reduces the population and subsequent crop damage (Maniania *et al.*, 2003). In Ethiopia, Tsedeke Abate (1986) reported that thrips population is low during the rainy season, from June to August and starts rising in September, highest from February through April and reaches its peak in April which is associated with maximum temperature and decreasing humidity and rainfall at Melkassa.

2.2.3 Feeding habit, cultivated and wild host plants of thrips

Feeding by thrips is not confined only to areas on leaves, but extends to all vegetative parts of plants. They usually concentrate on the rapidly growing tissues. Infestation depends upon the quality of the food, physiological age, protection afforded and the nature of environmental stress, particularly water stress (Suman *et al.*, 1980). These factors result in different distribution

patterns on the leaves of the same plant, as well as in the varying susceptibilities of the different plants to infestation.

Thrips tabaci is extremely polyphagous, feeding on wide range of host plant species (Waterhouse and Norris, 1989; Doederlein and Sites, 1993). They inhibit the growth of leaves, shoots and flowers of many cultivated crops as well as uncultivated plants in at least 25 families. It is considered a major pest of open field crops like onions, leaks and garlic, cotton, tobacco, cucumber, black pepper. Secondary hosts includes crucicferous crops, aspargus, sugar beet, rape, pigeon pea, safflower, melon, tomato, cassava, Mango, Pyrethrum, bean, potato, Grapevine and fodder crops(Harris *et al.*, 1936; Shelton, 1995). In Ethiopia onion, leak, cabbage, tomato, hot pepper, tobacco, beetroot, cotton, beans, sorghum and weed species cyprus were reported to hosts *T. tabaci* in the upper Awash area (Tsedeke Abate, 1986).

2.3 Economic Importance of *Thrips tabaci* L.

Of an estimated 8000 extant species of thrips (Palmer and Mound, 1979) and more than 5500 species that are described, scarcely 1% is recorded as serious pests. Thrips can be pestiferous in various ways as irritants to field workers or the public, as contaminants in a variety of situations, by direct plant damage affecting yield or cosmetic appearance, as vectors of plant diseases and as perceived quarantine risks that negatively impact trade.

2.3.1 Primary damage on the crop

On a worldwide basis, *T. tabaci* is recognized as far the most destructive onion pest (Jones and Mann, 1963; Srinivasan *et al.*, 1981; Sinha *et al.*, 1984). Its depredations extend to many commercial and food crops, such as cotton, cabbage, tobacco, pea, cucumber, melon, lettuce, potato, tomato,

cornation, chrysanthemum, leakand garlic (Anyango, 1987; Loomans *et al.*, 1995; Parella and Lewis, 1997).

Thrips tabaci derives its common name from the severity of its attack upon the foliage of the onion plant, in both the tropical and temperate regions (Speyer, 1934). Feeding damage on onion has been described by various authors (Childers, 1997; Chishlom and Lewis 1984; Hemming, 1978; Mound and Marullo, 1996). The silvery patches develop along the inner angles of the onion leaves, which eventually curl (Childers, 1997). Later during the plant growth, the silvery patches (streaks) turn brownish as tissues dry up beneath the epidermis ultimately inducing premature leaf fall (Gabn, 1948; Ananthakrishnan, 1993). Because of the leaf damage, the plant loses more water than normal, through the damaged tissues and cannot adequately photosynthesize.

Damage done by thrips on onion has been distinguished from spider mites damage by the appearance of dark green faecal deposits, while spider mites produce black granules (Loomans *et al.*, 1995; Palmer, 1990). Thrips larvae have also been observed to excrete sticky droplets onto the leaves on which black sooty mould can grow (Palmer, 1990). The most serious effect of thrips infestations on onion is the resultant reduction in bulb yield. For example, Raheja (1973) and Mail *et al.,* (1985) recorded 50% yield losses due to onion thrips in Nigeria and India, respectively. In Portugal, Boica *et al.*, (1987) showed that onion thrips were responsible for a yield loss of 62% while in Brazil, Domiciano *et al.*, (1993) reported 40% yield loss due to onion thrips infestation. In Quebec (Canada), heavy infestation by onion thrips resulted in onion yield loss of 43% and 34.5 % in 1988 and 1989, respectively (Fournier *et al.*, 1995). In Kenya trials carried out recently estimated onion yield losses ranging from 38 to 54% (Ampong and Sithanantham, unpubl.). Tsedeke Abate

(1983) reported an overall yield loss of 33.5 % in the Awash valley onion growing area.

The stage of growth of the onion plant when infestation occurs seems to determine the extent of yield loss. Early and late season infestations diminish yields less than those occurring in mid–season during the bulbing stage (Francois *et al.*, 1995).

2.3.2 Effects as vectors of plant diseases

In addition to causing direct damage to plants through feeding on parenchyma cells, thrips are also primary vectors of various tospoviruses, such as tomato spotted wilt virus (TSWV), tomato Chlorotic Spot virus (TCSV), ground nut ring spot (GRSV), ground nut bud- necrosis (GBNV) and Iris Yellow spot (IYSV). Tospoviruses causes serious damage to plant species in a wide range of families and are transmitted in nature only by thrips. Moreover, successful transmission depends on an individual thrips acquiring the virus while it is a first or an early second-instar larva; adults cannot acquire and transmit tospoviruses (Moritz *et al.,* 2001).

Studies on the role of *T. tabaci* on onion disease have demonstrated an association between thrips population, bacteria and fungal pathogens such as purple blotch, *Alternaria porri* (Bhangale and Joi, 1983; Mayer *et al.*, 1987; Ananthakrishnan 1993), and leaf blight caused by *Botrytis squamosa* (Krauthausen, 1989).

2.4 Monitoring and Economic Threshold

Monitoring to identify when thrips arrive and to determine population level is helpful in designing an appropriate control strategy. In onions, thrips generally migrate into a field when plants in surrounding areas begin to dry, so monitoring efforts should be timed accordingly. Hence it is important to identify the efficient and precise sampling methods for estimating the population density of thrips in research and pest management. Once the migration has begun, individual onion plants in several section of the field should be determined. To find thrips, the leaves must be parted to reveal the youngest emerging leaf in the center of the plant. Thrips prefer this area because it is the most succulent part of the plant and provides excellent protection from weather and insecticides. Adult thrips may also be found on older leaves, particularly where leaves have folded over, providing a shelter area (Lewis, 1997).

Areas where thrips are most likely to be found are the field borders, near woods or in the vicinity of grain or field borders. At least 50 plants should be examined when scouting leaf stage (Hoffman *et al.*, 1996). It is also necessary to estimate the average leaf stage of the crop prior to plant sampling. One has to carefully record the approximate number of thrips per plant that they find. Then is divided by total average leaf stage of the crop to give you a "thrips per leaf" estimate. In California, a threshold of 30 thrips per plant at mid-season has been used successfully (Coviello *et al.*, 1993). This number would be adjusted down wards from young plants and upward for large, mature plants. In New York State a conservation action threshold of three thrips per leaf has been suggested (Hoffman *et al.*, 1996).

The number present can be used to determine action thresholds for applying control strategies. Coviello *et al.,* (1993) note that reliable treatment threshold

levels for onion are speculative when considering appropriate action threshold levels, it is important to remember that no single number will always be a reliable guide. Climate is a factor, hot and dry conditions favor thrips damage and cool rainy weather hinders it. In drier years fewer thrips per leaf can be tolerated before yield losses result.

Various procedures including direct field count, mechanical or tapping methods of dislodging thrips, sticky trap, irritation methods based on the repellent effect of certain chemicals or heat, removal and washing of whole plants are used for sampling thrips from plants in the field (Lewis, 1973). To detect early infestation, a crop-scouting program that includes both sticky trap cords and visual inspection are critical. Scouting should be done once a week, and more often when an infestation is detected. Regular scouting is also necessary to monitor the efficacy of control measures (Bocak, 1996).

A hand lens is a useful tool to detect live thrips as well as signs of thrips activity (e.g. black feces, and silvery, flecked areas on leaves). Hot-pink sticky cards have been found to be the most attractive color for trapping thrips, though blue and yellow are often still used. Sticky traps should be placed 1 to 2 inches above the crop canopy so that the bottoms of the traps are just above the crops, at the rate of one or two per 1,000 ft^2 (Davis et al., 1995).

2.5 Management of *Thrips tabaci* L.

2.5.1 Biological Control

Large spectrums of natural enemies are known to attack thrips. Reports on natural enemies attaching onion thrips are relatively scarce compared to other species of thrips. However the reported natural enemies basically fall apart in two groups: macrobials (predators: Riudavets, 1995; Parasitoids: Loomans *et al.*, 1997) and microbials (entomopathogens: fungi (Butt and Brownbridge, 1997) and nematodes (Loomans *et al.,* 1997).

Predators are the main natural enemies of *T. tabaci*. They are mostly generalists (i.e. they don't restrict their feeding activities to thrips), but also feed on other plant-inhibiting arthropods including beneficial species. More than 30 species of predators belonging to the family Antocoridae, Miridae, Staphylinidae, Syrphidae, Gryllidae, Chrysopidae, Coccinellidae Malachidae, and Phytosciidae were listed as preying on onion thrips (Riudavets, 1995). During the past two decades, most attentions has been paid to augmentative release of generalist predators like phytoseid mites (*Amblyselus* species) and Pirate bugs (*Orius* species). *Orius* species (insidiosus, tristicolar) (Heteroptera: Anthocoridae) were known as common thrips predators, which are found on a wide range of field crops, orchards as well as ornamentals (Herring, 1966). Various native *anthocorid* species were already known to enter greenhouses spontaneously during the summer periods in temperate areas, controlling infestation of *T. tabaci* (Ramakkers, 1978) or *Frankinella occidentalis* (Tellier and Steiner, 1990).

For quite some time, there has been renewed interest in the use of hymenopterous parasitoids as potential biological control agents of thrips pests. Classical biological control of thrips through inoculative release of

parasitoids has been tried in the past without much success. Efforts to incorporate thrips parasitoids into greenhouse integrated pest management programs by inoculating releases or inundation to control thrips pests are of a more recent date. (Riudavets, 1995; Tommasini, 2003).

Most of the thrips parasitoids are Hymenopteran Koinobionts allowing their host to develop beyond the attacked stage and mainly belong to the super family Chalcidoidea. They are solitary endoparastoids of eggs (Trichogrammatidae, Mymaridae) or larvae (Eulophidae), although sometimes the prepupae and /or pupae may be attached. Currently 27 species are described, parastizing over 70 species of Thysanoptera (Loomans and Van Lenteren, 1995). A few species in the genera Psilogaster and Orasema (Euchoritidae) are reported as ectoparsites of thrips larvae (Beshear, 1974; Johnson, 1988). Parasitoids attacking Thrips eggs, except for *polynema indica* (Mymaridae), all belong to the genus Megaphargma (Trichogrammatidae) (Lin, 1992).

Two groups of pathogenic microorganisms have been reported to attack onion thrips in nature and these are the parasitic nematodes and entomopathogenic fungi (Butt and Brownbridge, 1997; Loomans *et al.,* 1997).

Fungi are the commonest pathogens reported from thrips including *T. tabaci*. They include *Neozygites parvispora* (Macleod *et al.,* 1976; Butt and Brownbridge, 1997), *N. cucumberiformis* (Bourne and Shaw, 1934), *Zoophthora radicans* (Bourne and Shaw, 1934), *Entomophthora thripidum* (Samson *et al.*, 1979), *Verticillum lecanii* (Ekbom, 1979; Binns *et al.,* 1882). *Beauveria bassiana* (Dyadechko, 1977), *Paecilomyces fumosoroseus*, *Metarhizium anisopliae* (Fransen, 1990) and *Sparothrix* species. The

saprophytic fungus *Aspergillus* has also been reported on the onion thrips (Dyandechko, 1977).

The mode of infection of entomopathogenic fungi is to infect their host through the cuticle. Their performance over a range of environmental conditions and their ease of mass productions, render them an attractive option for the management of thrips (Butt and Brownbridge, 1997).

2.5.2 Synthetic Chemical control

Chemical control is the most frequently used method to suppress and control thrips pest population. Thrips pests are difficult to control using chemicals (Lewis, 1997), owing to the hidden feeding and reproduction niches (immature development stages are not exposed to insecticide contact, eggs are embedded in the leaf; pupal stages are protected in the soil, dirt or debris). Furthermore, most chemicals have a short-term effectiveness and frequent spraying is required for an effective control. However, studies on the effects of various insecticides on onion yield have demonstrated contrasting results. For example, some authors have reported that control of thrips with insecticides didn't increase onion yield (Lorini and Ferreto, 1991; Goncalves, 1997). On the other hand, Mail *et al.*, (1985), and Bocak (1996) reported increased onion yield due to insecticide use.

In the early part of this century, not much could be done to prevent a building up of *F.occidentalis* or *T. tabaci* population. Sulfur, nicotine, derris and paris green were originally used as insecticides to control thrips (Richardson, 1934) but these only reduced numbers. Chemical control of thrips pests really started with the application of tartar emetic combined use with brown sugar (Richardson, 1934). Mean while there is an extensive amount of literature on the chemical control of *T. tabaci* and *F. occidentalis*

(Lewis, 1997). Seed treatment and seeding depth are reported to effectively suppress the population of *T. tabaci* and were shown to provide healthy plants at the time of transplanting (Allan, 1964; Ester and Huiting, 2001).

The effectiveness of soil applied granular systemic insecticides on *T. tabaci* was reported in India (Sinha *et al.,* 1984). Pakistan (Zaman and Shah, 1989), Taiwan (Chang 1991) and eastern Washington, U.S.A (Getzin, 1973). However, comparative efficacy of granule and EC formulations showed that, EC formulations were more efficacious and economic to use (Butani and Kapadia, 1999).

Economic threshold and economic injury levels are important components of an integrated pest management program (Hoffmann, 1996). They are useful for the timing of possible insecticide application and for determining thrips densities for effective biological control (Shipp *et al.*, 1998). Studies on the appropriate time of chemical control of *T. tabaci* in Germany (Krauthausen *et al.,* 2001) showed that the use of threshold levels could decrease chemical control by more than 50% without reducing yield or the onion quality. The studies also demonstrated that productivity of plots with preventive weekly treatments did not differ from that of the plots treated when the population reached 25 insect per plant. Consequently, the authors concluded that proper management of *T. tabaci* on onion required determination of their effect on the yield and the establishment of an economic threshold.

In Kenya several insecticides have been evaluated for their efficacy against onion thrips (Anon, 1964; Allan, 1964). However most of the insecticides earlier tested are obsolete due to their environmental hazards.

In Ethiopia, dipping of seeddings in 0.1% a.i solution of diazion before transplanting and field spray with the synthetic pyrethroids, cypermethrin and decamethrin have given satisfactory control of insects in the Awash Valley (Tsedeke Abate, 1983). Spray with endosulfan, fenitrothion and phenthoate at 10 to 14 day interval have been reported to give effective control of onion thrips (Crowe and Shitaye, 1977).

2.5.3 Cultural control

Cultural controls are techniques developed from crop management or mechanical practices that can be readily manipulated to disadvantage pest population growth while having limited adverse effect on crop productivity (Edwards *et al.*, 1990). Cultural control strategies have not been widely adopted for thrips management in out door crops, but techniques based on sanitation and manipulation of indoor environment are employed more rigorously in the greenhouse industry because of high value of the crops grown, smaller areas that require treatment, and greater practicality of implementation (Jacobson *et al.,* 2001).

Cultural practices reportedly adopted against *T. tabaci* have played an important role in reducing thrips population on onion and various other crops. Destruction of piles of cull onions between crops reduces the abundance of this pest along with other sanitation techniques such as removing weeds in the field and outlying area (Anonymus, 1992). Rotation or interplanting with non-host crops can also be effective in deterring lager population buildup (Soni and Ellis, 1990). Intercropping of different crops with onion (Theuniessen and Schelling, 1998) significantly reduce onion thrips population. While intercropping onions and garlic or with tomato in Egypt (Afifi and Heydar, 1990) and leek with ryegrass in Germany (Weber *et*

al., 1999) decreased the level of thrips on onion, garlic and leeks respectively. Adjusting planting seasons and irrigation of onion is very important to control thrips. Delayed planting in Egypt (El-Gendi, 1998) and USA (Stoner and Shelton, 1988) was reported to reduce the rate of infestation and increased yields on onions and cabbages respectively. On the contrary, delayed transplanting date in Brazil (Goncalves, 1997) increased *T. tabaci* infestation and yield loss on onions. Direct seeding of onions prolongs the growing season in the field and susceptibility to thrips infestations (Theuniessen and Schelling, 1998).

2.5.3.1 Integrated Biofarm and organic pest control

The integrated Biofarm concept is a nature based natural resources management, food production and environment restoration (Getachew *et al.*, 2002). The basic principles of the Biofarm concept include among other; return what ever you take; work with nature rather than against nature, co-operation rather than competition and the use of indigenous knowledge. It clearly demonstrates that ecological factors influence or limit the economic and cultural components of the society. The Biofarm agriculture is a sustainable agricultural system which optimize agricultural outputs while minimizing external inputs (like excessive water, chemical insecticides and fertilizers) to protect and enhance the environment (Getachew *et al.*, 2002).

Organic pest control emphasizes mainly on the preventive aspect of problems happening rather not to treat once it emerges. In contrast to other control strategies, this farming tolerates some pest populations while looking the long haul (Bowman, 1997). It is production management system that promotes and enhances agro-ecosystem health, including biodiversity, biological cycles and soil biological activity (Getachew *et al.*, 2002). The system emphasize the use of management practices in preference to the use of off farm inputs, taking into account that regional conditions require locally adapted systems.

This is accomplished by using agronomic, biological and mechanical methods as opposed to using synthetic material, to full any specific function within the system (Cook, 1990).

This strategy creates a system that no one pest can gain a competitive advantage within the system through cumulative effect of many techniques (Klonsky *et al.*, 1994). The major organic pest control techniques include:

- Allowing for an acceptable level of pest damage.
- Encouraging predatory beneficial insects to flourish and feed on pests.
- Planting companion crops that discourage or divert pests.
- Using row covers to protect crops during pest migration periods.
- Rotating crops to different location from year to year to interrupt pest reproduction cycles.
- The techniques also provide additional benefits: soil protection and improvement, fertilization, pollination, water conservation, season extension, etc. and these benefits are both complementary and cumulative in overall effect of term health

2.5.4 Host plant resistance

As the pressure to reduce pesticide use increases and better breeding methods utilizing manipulative molecular techniques are developed, the economic viability and incentive to develop and use resistant plant verities for insect management may increase (Birch, 1997; Eigenbrode and Trumble, 1994). Substantial research has focused on evaluating field or vegetable crop plant verities tolerant or resistant to thrips, but with some exceptions progress has been slow (Bowmen and McCarty, 1997; Frei *et al.*, 2004).

Past efforts in identifying and utilizing host plant resistance to onion thrips are apparently very limited. Mostly, the focus has been on testing a limited set of genotypes and identifying those, which show some advantage in terms of thrips infestations or damage severity. Research at Asian Vegetable Research and Development Centre (AVRDC), in screening a worldwide collection of onion germplasm showed no distinct source of resistance for onion thrips.

Morphological and anatomical characters which have been reported to affect population include orientation of leaves and glossiness of foliage cultivars with a relatively wide angle of leaf emergence have been found to hold smaller thrips population than those with a smaller angle of leaf emergence (Patil *et al.*, 1988, Coudriet *et al.,* 1979). In susceptible varieties the young blade leaves generally have one flat side, which is closely pressed to the flat surface of the opposite leaf, thus providing many crevices into which the thrips can creep for protection. Jansen (1995) has indicated that the red onion varieties are more sensitive to thrips damage than yellow varieties. The possible reason

fro low thrips infestation on yellow varieties were attributed to the foliage color being less green and spreading nature of leaves besides the earliness of these varieties in maturity (Patil *et al.*, 1988).

Among onion genotypes reported so far the less susceptible to onion thrips in India are Pusa red, N_53 (Sinha *et al.*, 1984) genotypes PBR3, PBR4, VLI NO 18, NO 19 and Pusa ratnar. In Egypt, El-Gendi, (1998) reported cultivars Giza 6, Behiri, Granex 33 and Quetta to be less susceptible to onion thrips while in Brazil Boica *et al.,* (1987) reported cultivars Texas Grano, Baia do decdo and Granex 33 to be least infested by onion thrips.

3. MATERIALS AND METHODS

3.1 Description of the study site

The study was conducted in the Luke Kebele ICIPE research site in Chaha Woreda, which is located about 190 kms Southwest of Addis Ababa in Gurage Zone of SNNP (Fig.2). The area has an altitude ranging from 1763 m.a.s.l and grid references of N 035^0 25' 32" latitude and E 37.0 35' 35" longitudes (Fig.3). The study site receives a bimodal rainfall with a short rainy season from April to June and a long rainy season from July to October with the average annual rainfall of 1194.1 mm and mean annual maximum and minimum temperature of 28.7^{o}c and 13.28^{o}c, respectively (Appendix 1 and Appendix 2). The vast and fertile low land and the rainfall pattern allow farmers to grow crops twice a year. The farming system is mainly based on the cultivation of Ensete (*Ensete ventricosum* W. Cheesm.) as a subsistence food crop inter-cropped with maize (*Zea mays* L.), Sorghum (*Sorghum bicolar*) and cabbage (*Brassica oleracea* var.). Additionally, some farmers also grow teff *(Eragotis teff)* and other cash crops like chat (*Catha edulis*) and coffee (*Coffea arabica*,).

The research site was established in 1997.Vegetable production was introduced in the area with the establishment of the site. Since then the nearby farmers have been given an intensive training on basic vegetable production. The research site station also supplement healthy and vigorous seedlings and farm technologies in which farmers can produce at household level. The production is gradually increasing through time. Among the cultivated vegetable crops, onion is second to kale (*Brassica oleracea L.var acephala*) due to its nutritional importance in the area.

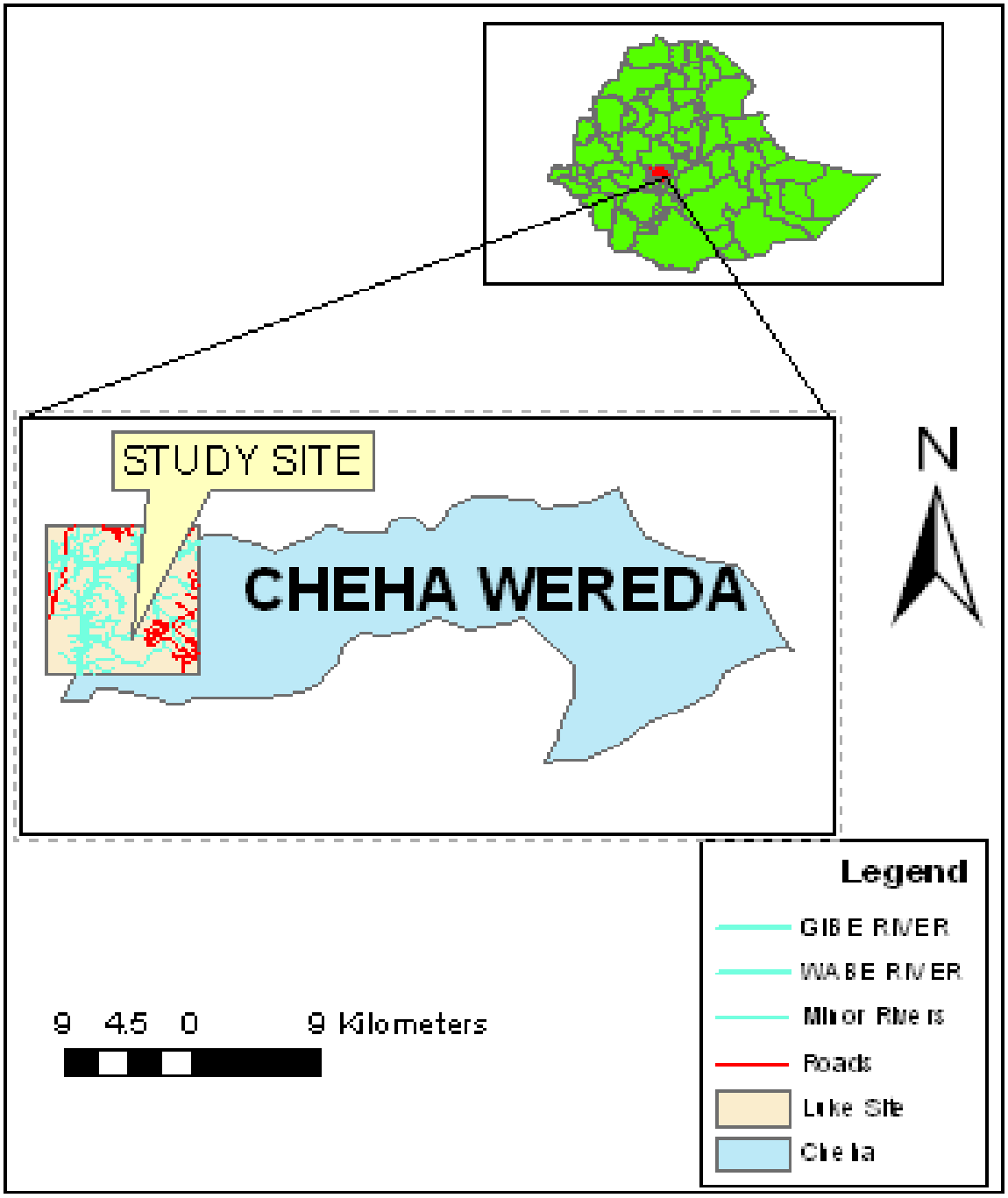

Figure 2. Map of the study area

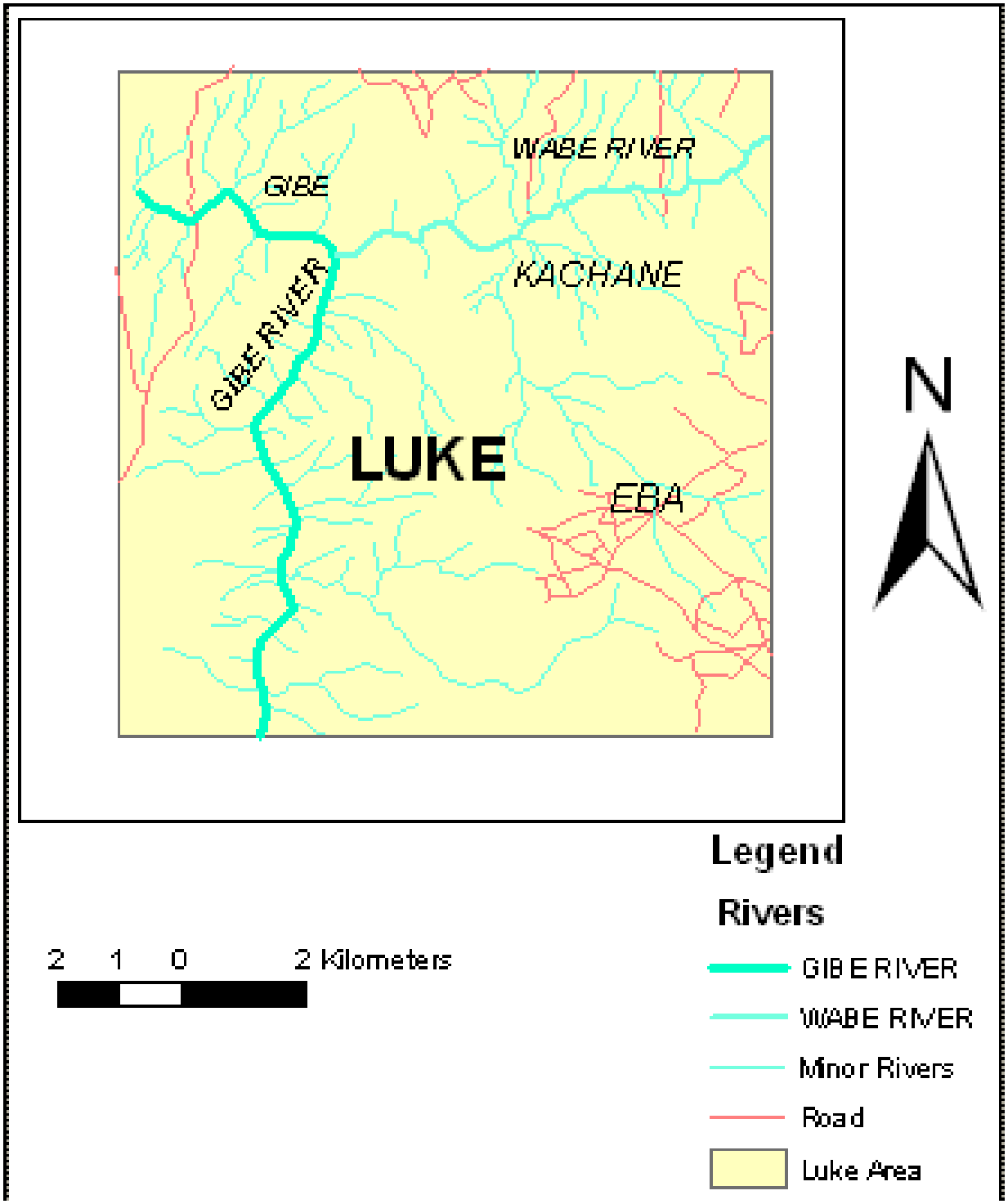

Figure 3. Map of the Luke site

3.2 Field preparation and planting procedures.

The study on the properties (Classification, profile and Characteristics) of the soil was conducted by taking samples from the upper 30cm. The soil is well drained sandy clay loams, with organic manure content of 2.36%, and P^H (H20) 6.7. It has total N content of 0.87%, P and K level of 1540 ppm and 1672 ppm respectively.

The field experiments were carried out on a 0.5 ha piece of land with access to drip irrigation (Plate 1). Digested organic manure (Slurry) from the livestock were used at a recommended rate of 20 tons/ha three months prior to transplanting and during transplanting. The applied manure was incorporated in to the soil and spacing of the onion crop was kept according to the treatments. Beds were prepared using double digging techniques and drip irrigated every day throughout the study period (Getachew *et al.*, 2002).

Plate 1. Part of the experimental field layout of the study site

3.3. Experimental design and sampling methods

3.3.1 Experiments on the Effect of Manure application and plant spacing on infestation and damage by *Thrips tabaci*

Onion seedlings were first transplanted to experimental plots of $10m^2$ (1m x 10m) size. Application of digested organic manure from livestock at a rate of 20 tons/ha before and after transplanting were used as treatments in combination with different plant spacing between rows and hills. The experiment was laid out using factorial randomized complete block design (RCBD) with three replications. The treatment combinations and the rate of application used in field experiments include: Manure Application Before Transplanting (MABP) (20ton/ha) and Manure Application at Transplanting (MAT) in combination with 20cm spacing between rows and with 20 cm, 25 cm or 30 cm spacing between plants, respectively. Plots not receiving any organic manure served as untreated controls.

Destructive sampling was used and five plants were selected randomly from each plot at 15 days interval until harvest. At sampling, the randomly selected plants were taken covered using plastic bugs, cut at the ground level and thrips were counted by splitting the leaves.

Number of thrips larvae and adult per leaf, leaf number and size were recorded. Leaf damage was determined based on a visual rating scale, whereby 20-40% leaf surface area affected by thrips feeding was considered as mild, 40-60% leaf area affected as intermediate and above 80% as sever case (Talekar, 1999).

In cage experiments, Onion seedlings were transplanted in plastic buckets of 20cm height and 20cm in diameter on soil with organic manure application before planting (BPMA), and after transplanting (ATMA), respectively.

Seedlings transplanted in plastic buckets on soil without any organic manure application were used as controls. All onion seedlings in pots were covered with cheesecloth size to exclude infestation by thrips from other sources and keep introduced thrips confined to pot. Onion plants were immediately infested by introducing five thrips adults per onion plant into the cages. Experimental plants in cages with treatment combinations were then arranged in complete randomized design with five *T. tabaci* replications. Onion plants were examined every 15 days using hand lens (10x) for the presence of larvae and adults of *T. tabaci*.

Direct thrips count was done manually by splitting onion leaves from randomly selected onion plants in cage. The infestation level of thrips per plant and leaf damage were computed and recorded for data analysis (Plate 2).

Plate 2. Cage experiment and direct counting of onion thrips from pot Plants.

3.3.2 Survey on the composition of predatory beneficial insects complex associated with onion in the study site.

During the study on field experiments, plants included in the samples were examined for the presence and activity of predatory natural enemies at sampling to assess their importance as biological agents of *T. tabaci*. Insects colleted on onion plants at sampling were preserved in vials with 95% alcohol for identification using keys in the laboratory.

3.3.3 Field survey on cultivated and wild host plants of Onion thrips in the study area

To determine alternate hosts of onion thrips, plant samples were taken randomly from cultivated crops and weeds found in the study area. Weed plant samples were taken using 0.5 m x 0.5 m quadrants from each wild species and onion. Twenty-five plants were randomly selected, using destructive sampling method and examined for larvae and adults of *T. tabaci* using a magnifying hand lens (12X). The same procedures were applied for the cultivated plants grown near onion field in which 25 plants were randomly sampled and examined.

The mean number of thrips per plant and percent infestation level were determined for the cultivated and wild hosts after identification. The sampling was carried out in April and unidentified specimens were taken to the National Herbarium, Department of Biology, Addis Ababa University and identified.

3.3.4 Data analysis

Data gathered from the experiment on the number of larvae and adults, and yield loss of fresh weight of the bulb would be analyzed using parametric paired t-test procedure in SPSS version 11 and subjected to analysis of

variance (ANOVA). Means were separated using Duncaun Multiple staudentized range Test of MSTATC statistical software (Freed, 1993). Relationship between mean numbers of thrips averaged across sample dates and damage on marketable yield were determined. Furthermore other cultural variables including irrigation were also recorded.

4. RESULTS

4.1 Effect of manure application and plant spacing on the infestation levels of *Thrips tabaci* at early stages of the crop

Data on the number of *Thrips tabaci* obtained from onion plants on soil with organic manure and different plant spacing at 15 and 30 days after transplanting is presented in Table 1. The analysis of variance of the data on the number of thrips per plant indicated that there were no significant differences on larvae and adults per plant among treatments at 15 days and 30 days plant age after transplanting (P>0.05)(Appendix 3). Treatments with before transplanting manure application (BTMA) at 20x30cm and at transplanting manure application with 20x30cm line spacing had the lowest adult number per plant. The highest number of adult per plant was recorded from the untreated control check with 20x25cm, and at transplanting manure application with 20x20cm plant spacing (Table1).

Table 1. Number of *Thrips tabaci* (±SE) obtained from onion plants on soil with organic manure and different plant spacing at 15 and 30 days after transplanting.

Treatments	BTMA & 20X20cm	BTMA & 20X25cm	BTMA & 20X30cm	ATMA & 20X20cm	ATMA & 20X25cm	ATMA & 20X30cm	WOM & 20X20cm	WOM & 20X25cm	WOM & 20X30cm
15 DAT									
Mean count									
Adult	4.7±0.78	4.9±0.97	3.6±0.38	5±0.5	4.1±0.55	3.4+1.05	6.5±0.48	4.5±0.35	3.6±0.62
Larvae	1.6±0.32	1.3±0.27	1.3±0.03	1.5±0.35	2.1±0.57	1.6±0.19	2.3±0.66	2±0.31	1.6±0.21
Total	6.27±1.09	6.2±1.11	4.8±0.41	6.4±0.59	1±0.18	5±1.10	8.87±0.98	6.5±0.29	5.2±0.46
30 DAT									
Mean count									
Adult	9.1±1.09	6.2±1.03	4.8±0.36	9.5±0.72	6.1±1.77	4.8±1.34	11.2±1.99	7.8±2.19	6.8+0.73
Larvae	8.1±0.52	8.4±2.29	8.6±0.63	9±0.32	9.2±1.9	9.3±3.08	11.9+3.16	13±4.33	12.8±3.48
Total	17.2±1.59	14.6±3.3	13.4±0.95	18.5±1.04	15.3±3.67	14.1±4.43	23.2±5.1	20.8±6.36	19.6±4.16

BTMA =Before Transplanting Manure Application
ATMA= At Transplanting Manure application
WOM = Without Manure application
20X20cm, 20x25cm, 20x30cm = Inter and intra spacing of onion plants

4.2 Effect of manure application and plant spacing on the infestation levels of *Thrips tabaci* at 45 and 60 days old stages onion crop

Data on the number of *Thrips tabaci* from onion plants on soil with organic manure and different plant spacing at 45 and 60 days after transplanting is given in Table 2. Analysis of variance of the data indicated that there was significant difference in the mean number of onion thrips and the mean number of adult and larvae thrips per onion plant among the treatments at 45 days and 60 days of plant age after transplanting ($P<0.05$) (Appendix 3). Treatments with before transplanting manure application (BTMA) at 20x30cm and 20x25cm had lower mean count of larvae and adults of *T. tabaci* followed by the treatment at transplanting manure application with 20x30cm plant spacing (Table 2). On the other hand, the untreated control with 20x20cm plant spacing had the highest mean count of larvae and adults of *T. tabaci*. Before planting manure application with 20x30cm, 20x25cm line spacing had the lowest mean infestation respectively at 60 days of plant age after transplanting. Further more the control treatments with 20x20cm and 20x25cm spacing revealed the highest mean infestations.

Table 2. Number of *Thrips tabaci* (±SE) obtained from onion plants on soil with organic manure and different plant spacing at 45 and 60 Days after transplanting.

Treatment	Mean count		
45 DAT	**Larvae ± SE**	**Adult ± SE**	**Total ± SE**
BTMA & 20X20cm	44.7±14.7**abcd**	19.3±2.09**ab**	64±16.9**abc**
BTMA & 20X25cm	36.9±8.45**ab**	11.9±1.27**ab**	48±9.57**ab**
BTMA & 20X30cm	28.5±9.86**a**	7.3±0.82**a**	35.9±10.37**a**
ATMA & 20X20cm	59.7±5.79**abcd**	18.8±1.63**ab**	78.5±7.26**abcd**
ATMA& 20X25cm	58.7±9.1**abcd**	24.9±9.49**bc**	83.6±16.6bcd
ATMA & 20X30cm	40.3+5.29**abc**	17.1±2.24**ab**	57.4±7.26**abc**
WOM & 20X20cm	73.3±15.37**d**	35.1±6.83**c**	108.4±22.13**d**
WOM & 20X25cm	71.3±6.03**cd**	24.9±5.98**bc**	96.1±11.99**cd**
WOM & 20X30cm	63.2±0.61**bcd**	13.2±1.31**ab**	76.4±1.17**abcd**
60 DAT	**Larvae ± SE**	**Adult ± SE**	**Total ± SE**
BTMA & 20X20cm	25.5±1.33**ab**	21.5±1.**28abc**	47± 2.53**ab**
BTMA & 20X25cm	22.2±4.76**a**	14±1.24**ab**	36.1±5.87**a**
BTMA&20X30cm	15.7±4.22**a**	11.7±2.59**a**	27.3±6.81**a**
ATMA & 20X20cm	36.9±6.59**bcd**	22.5±5.19**bc**	59.4±11.46**bc**
ATMA & 20X25cm	40.7±0.87**cd**	17.9±2.08**ab**	58 ±1.22**bc**
ATMA & 20X30cm	28.2±6.74**abc**	15.6±4.99**ab**	43.8±11.68**ab**
WOM & 20X20cm	45.3±4.10**d**	29±4.5**c**	74.3±3.23**c**
WOM & 20X25cm	42.2±1.27**d**	22.1±0.93**abc**	64.3±1.00**bc**
WOM & 20X30cm	40.8±1.11**cd**	17.1±0.74**ab**	57.9±1.73**bc**

Means in the column with the same letter are not statistically different (p> 0.05), Duncan's Multiple range honestly significant different test
BTMA =Before Transplanting Manure Application
ATMA= At Transplanting Manure application
WOM=Without manure application

4.3 Effect of manure application and plant spacing on the infestation levels of *Thrips tabaci* at 75 and 90 days old stages onion crop

Data on the mean number of *Thrips tabaci* from onion plants on soil with organic manure and different plant spacing at 75 and 90 days after transplanting are presented in Table 3. There was also a significant ($P<0.01$) (Appendix 3) difference among treatments at 75 days after transplanting in the mean number of larvae and adults of *Thrips tabaci*. Plots with manure application before transplanting at 20x30cm and 20x25cm spacing exhibited the lowest infestation levels. On the other hand, untreated plots with 20x20cm plant spacing and plots that received at transplanting manure application with 20x20cm plant spacing had the highest infestation level (Table 3).

The analysis of variance of data on number of larvae and adults of *Thrips tabaci* at 90 days of plant age after transplanting showed that there was a significant ($P=0.001$) difference among treatments in the mean total number of thrips and number of larvae and adults of *Thrips tabaci*, respectively. The lowest total number of thrips was recorded by treatments of manure application before transplanting at 20x30cm, and 20x25cm plant spacing and the highest infestation by the control treatments (Table 3) (Appendix 3).

Table 3. Number of *Thrips tabaci* (±SE) obtained from onion plants on soil with organic manure and different plant spacing at 75 and 90 days after transplanting.

Treatment	Mean count		
75 DAT	**Larvae ± SE**	**Adult ± SE**	**Total ± SE**
BTMA & 20X20cm	17.9±5.24**ab**	10.3±2.27**abc**	28.3+7.45**abc**
BTMA & 20X25cm	13.8±1.63**ab**	7.07±1.18**ab**	20.9±2.78**ab**
BTMA&20X30cm	11.3±1.77**a**	5.6±1.11**a**	16.9±2.88**a**
ATMA & 20X20cm	22.7±1.59**bc**	14.9±1.74**cd**	37.4±3.34**cd**
ATMA&20X25cm	17.7±2.23**ab**	9±0.46**ab**	26.7±2.63**abc**
ATMA & 20X30cm	15.9±2.0**ab**	7.7±0.77**ab**	23.7±2.77**abc**
WOM & 20X20cm	28.1+5.36**c**	17.1+2.84**d**	45.1±8.2**d**
WOM & 20X25cm	22.8±2.27**bc**	11.5±1.73**bc**	34.2±3.98**bcd**
WOM & 20X30cm	21±0.98**abc**	8.13±1.03**ab**	29.1±1.94**abc**
90 DAT	**Larvae ± SE**	**Adult ± SE**	**Total ± SE**
BTMA & 20X20cm	7.6±1.13**ab**	3.9±0.41**abc**	11.6+1.51**abcd**
BTMA & 20X25cm	5.4±0.72**a**	3±0.72**a**	8.4+1.44**ab**
BTMA&20X30cm	4±0.99**a**	2.1±0.52**a**	6.11+1.31**a**
ATMA & 20X20cm	7.9±1.65**ab**	6.5±0.87**cd**	14.5+2.51**bcd**
ATMA&20X25cm	7.4±1.25**ab**	3.9+0.93**abc**	11.3+2.17**abcd**
ATMA & 20X30cm	6.7±2.27**a**	3.1±1.57**ab**	9.7+3.84**abc**
WOM & 20X20cm	16±2.55**c**	8.7±1.17**d**	24.8+3.47**e**
WOM & 20X25cm	12.5±0.37**bc**	6.1±1.05**bcd**	18.5+1.12**de**
WOM & 20X30cm	11.9±1.68**bc**	4.6±0.23**abc**	16.4+1.90**cd**

Means in the column with the same letter are not statistically different ($p > 0.05$), Duncan's Multiple range honestly significant different test
BTMA =Before Transplanting Manure Application
ATMA= At Transplanting Manure application
WOM=Without manure application
20X20cm, 20x25cm, 20x30cm = Inter and intra spacing of onion plants

4.4 Evaluation of the impact of organic manure application on Onion thrips densities in cage experiments.

The data on the total mean infestation of *Thrips tabaci* from onion planted on soil with organic manure in cage experiment is presented in Table 4. Analysis of variance to determine the effect of organic manure application on the infestation level of onion thrips show that there was significant (P<0.01) (Appendix 4) difference in the number of larvae and adults of *T. tabaci* among the treatments. The lowest mean number of larvae and adults were obtained from manure application before transplanting followed by at transplanting manure application and the highest being the control with no manure application (Table 4).

Table 4. Number of *Thrips tabaci* (±SE) obtained from onion planted on soil with organic manure in cage experiment

Treatment	**Mean count**		
	Larvae ± SE	**Adult ± SE**	**Total ± SE**
BTMA	23.4 ± 0.93**a**	14 ± 1.41**a**	37.6 ± 0.066**a**
ATMA	24.4 ± 1.43**a**	16.4 ± 1.57**a**	41 ± 1.1**b**
WOM	30.4 ± 1.29**b**	16.6 ± 1.43**a**	47 ± 0.07**c**

Means in the column with the same letter are not statistically different (p> 0.05), Duncan's Multiple range honestly significant different test

BTMA = Before Transplanting Manure Application

ATMA = At Transplanting Manure application

WOM = Without manure Application

4.5 Effect of manure application and plant spacing on leaf size of onion plants infested with *T. tabaci* at different days after Transplanting

Data on average size of leaves of onion planted on soil with organic manure and different plant spacing at bulb forming stages (60, and 75 after transplanting) are given in Table 9.The analysis of variance of the data on the size of leaf per onion plant did reveal no significant difference among treatments at 15 and 30days after transplanting (P>0.05) (Appendix 5).

The analysis of variance of the data on the size of the leaf at bulb forming (60 and 75 days after transplanting) stage of onion plant resulted a highly significant difference (P<0.01) (Appendix 6) among treatments. Control treatments with out manure application at 20x20cm and 20x25cm line spacing had the least leaf sizes. On the other side, manure application before transplanting 20x30cm, and at transplanting manure application at 20x30cm plant spacing were recorded having the highest leaf sizes (Table 5).

Nevertheless, there is no significant difference in leaf number among all the treatments at the different days after transplanting (P>0.05) (Appendix 6).

Table 5. Average size of leaves of onion planted on soil with organic manure and different plant spacing at bulb forming stages (60, and 75)after transplanting.

Treatment	**Mean Leaf size**	
	Days After Transplanting (DAT)	
	60 DAT	**75 DAT**
BTMA & 20X20cm	25.8±0.11**bcd**	26.7±0.21**bc**
BTMA & 20X25cm	26.4±0.33**d**	28.2+0.15**d**
BTMA & 20X30cm	28±0.29**e**	30.4±0.49**e**
ATMA & 20X20cm	25.5±0.11**bcd**	25.7±0.28**ab**
ATMA & 20X25cm	26.3±0.79**cd**	27.3+0.23**cd**
ATMA & 20X30cm	27.7±0.08**e**	29.3±0.51**e**
WOM & 20X20cm	24.2±0.15**a**	25.5±0.36**a**
WOM & 20X25cm	25.1±0.14**ab**	25.9±0.32**ab**
WOM & 20X30cm	25.3±0.23**bc**	26±0.12**abc**

Means in the column with the same letter are not statistically different (p> 0.05), Duncan's Multiple range honestly significant different test

BTMA =Before Transplanting Manure Application

ATMA= At Transplanting Manure application

WOM = Without manure Application

20X20cm, 20x25cm, 20x30cm = Inter and intra spacing of onion plants

4.6 Effect of manure application and different plant spacing on the Leaf damage by onion thrips

Data on leaf damage by onion thrips infestation at 15, 30 and 45 days after transplanting are presented (Figure 4 and Figure 5). At the 15 and 30 days after transplanting, most plants were observed having mild leaf damage, except in the control treatments with an intermediate damage by onion thrips (Fig. 4).

The damage level had varied between sever and intermediate conditions in all the cases even though the leaves attacked varied based on treatments at 45 days after transplanting (Fig. 4). The severity of the damage continued also at 60 days after transplanting and become more serious in the control treatments with varying degree depending on the plant spacing (20x30cm, 20x25cm and 20x20cm) respectively (Fig. 5).

The damage analysis 75 days after transplanting was characterized by high intermediate attack in all the treatments followed by sever cases by most plants (Fig. 5). The severity even persisted 90 days after transplanting in which almost all plants exhibited an intermediate damage level followed by sever attacks (Fig. 5.

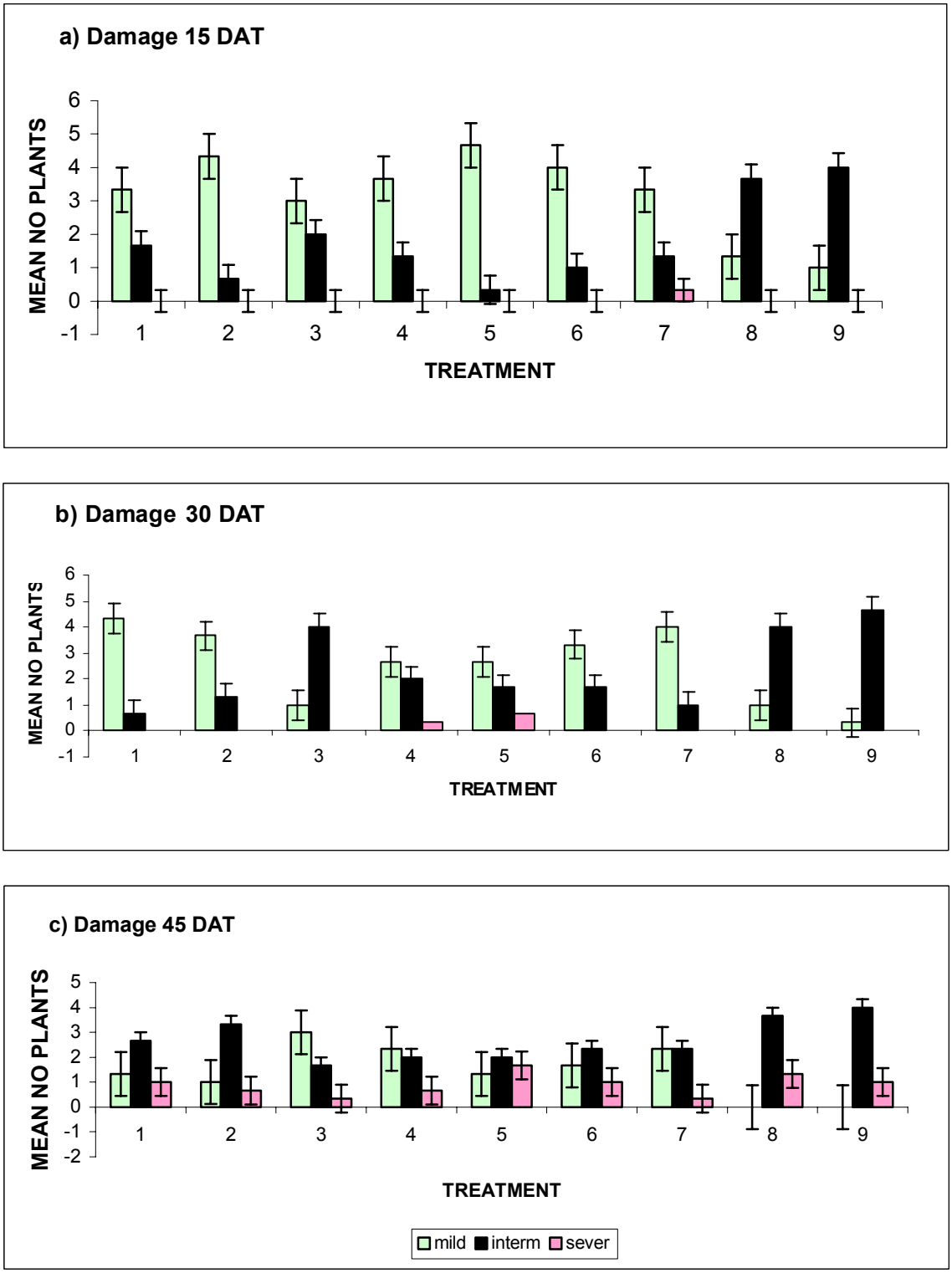

Figure 4. Leaf Damage by onion thrips Infestation at 15, 30 and 45 days after transplanting

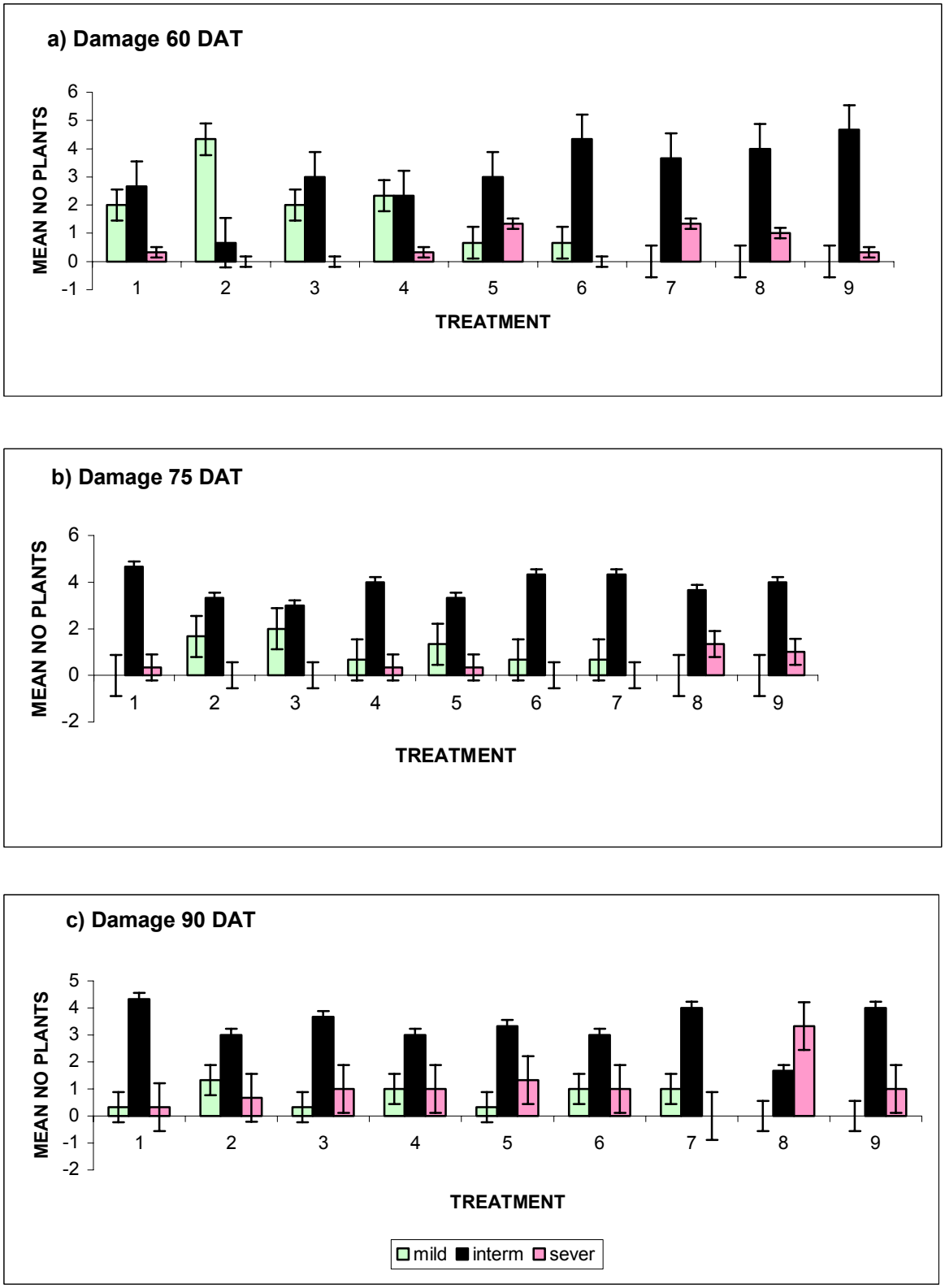

Figure 5. Leaf Damage by onion thrips Infestation at 60, 75 and 90 days after transplanting.

4.7 Alternate host range of onion thrips in the study area

The survey on alternate host plant of onion thrips in the study area indicated that, five cultivated vegetable plants; one cereal crop and four wild plants were found harboring larvae and adults of *T. tabaci.* Out of these, the five cultivated vegetables, the cereal crop and one wild plant were found to harbor the insect pest on their leaves.

As shown in the Table 6 below, the highest total infestation was recorded from Onion followed by Kale and wild Sorghum. According to the distribution of the cultivated vegetables in the farm, Kale occupied the largest area due to its nutritional demand and this had contributed for the occurrence of large number of onion thrips (Table 6).

Table 6. List of plants harboring *Thrips tabaci* L. and relative level of infestation in/ at and around Luke.

Common name	**Scientific name**	**Number of Onion thrips**	**%Total Inf^{n}**
Onion	*Allium cepa*	17.2	92.4
Kale	*Brassica oleracea L.var acephala*	5.8	23.5
Tomato	*Lycopersicon esculentum*	1.3	2.6
Cabbage	*Brassica oleracea*	1.4	3.2
Hot peeper	*Capsicum annum*	0.4	0.8
Maize	*Zea mays*	1.2	1.4
Wild Sorghum	*Sorghum arundinaccum*	3.7	5.3

4.8 Effect of manure application and plant spacing on the yield of onion due to *Thrips tabaci*.

Average yield of onion grown on soils with organic manure and different plant spacing under field conditions are given in Table 7. The analysis of variance of the data on the yield of onion showed a highly significant difference ($p<0.01$) (Appendix 7) among treatments. The highest yield was obtained from manure application before transplanting at 20x30cm and 20x25cm plant spacing. However, the minimum yield was recorded from the untreated control checks with 20x30cm and 20x25cm line spacing of the onion crop.

Table 7. Average yield of onion grown on soil with organic manure and different plant spacing under field conditions.

Treatment	Bulb yield (Kg/plot)+SE
BTMA & 20X20cm	4.0±0. 2**de**
BTMA & 20X25cm	4.7±0.2**f**
BTMA& 20X30cm	5. 2±0.2**g**
ATMA & 20X20cm	3.7±0.25**cd**
ATMA & 20X25cm	4.1±0.24**de**
ATMA & 20X30cm	4.25±0.25**e**
WOM & 20X20cm	3.43±0.08**bc**
WOM & 20X25cm	3.2±0.2**ab**
WOM & 20X30cm	2.97±0.16**a**

Means in the column with the same letter are not statistically different ($p> 0.05$), Duncan's Multiple range honestly significant different test
BTMA =Before Transplanting Manure Application
ATMA= At Transplanting Manure application
WOM = Without Manure Application
20X20cm, 20x25cm, 20x30cm = Inter and intra spacing of onion plants

4.9 Impact of the system on the predatory beneficial insects

The survey on impact of the farming system on the predatory beneficial insects showed that, three different generalist insects and spiders were identified in the field feeding on onion thrips larvae and adult starting 15 days after transplanting. The insects were identified as predatory mites (*Amblyseius cucumeris*) from chrysopidae family, pirate bugs of family Miridae (*Orius insidiosus*) species and ladybird bittel (Lady Bugs) of order colioptera and family coccinellidae.

5.DISCUSSION

The results from field experiments in this study showed that the mean number of *T.tabaci* on onion with manure application and different plant spacing differed significantly among the treatments applied. At 45, 60 and 90days of plant growth, there was a markedly reduced larval and adult thrips infestation on onion that were planted on soils that received organic manure application before and at transplanting in all plant spacing as compared to onion plants grown without manure application. Onion plants grown on plots without manure application at 20x20cm plant spacing suffered heavier infestations by *T. tabaci* at all plant growth stages.

In general, most onion plants in plots without manure application harbored highest number of thrips in contrast to those planted on soils before tansplanting manuare application irrespective of differences in plant spacing.

The results observed in this study agree with the findings of Erick (2002) that soil nutritional balance can reduce thrips attack. Soil fertility management may affect thrips infestation and damage; a lack of adequate soil calcium may invite higher population of thrips. High nitrate levels will also result in high thrips infestation. Before transplanting manure application resulted in the optimum soil fertility, in which healthy and vigorous onion plants with the least mean onion thrips count (Plate 3). Jerry *et al.* (1996); indicated that the right amount of nutrient in the soil would result in healthy, vigorous plants that are less affected by insect and disease. However, use of too much fertilizer can result in highly succulent plants and may encourage insect and disease problems.

On the other hand, the results from cage experiments indicated that onion plants grown in pots with soil that received no manure application showed significantly higher mean onion thrips counts compared to before and at transplanting manure application. And in most of onion plants grown on soil with manure application before and at transplanting, it was observed a significantly reduced total number of thrips.

According to Ware and McCollum (1980), the recommended application rates of barnyard manure is 15-20 tons per acre applied several months before transplanting. It was also supported by Pierce (1987) that onions require a substantial amount of nutrients and it is important to avoid over fertilization with nitrogen or phosphorous as this will contribute to increased pest problems. The findings in the present study contradicts with the work by Faheem *et al.*, (2003) in which the authors reported that low and optimum doses of inorganic nitrogen have no effect on thrips population but maximum mean total thrips infestation was obtained at high doses of nitrogen application.

The results on leaf size of onion plants on soil with organic manure and different plant spacing under field condition on bulb forming stages (60, and 75)of the onion plant indicated a markedly difference in the leaf size. Treatments with manure application before transplanting at plant spacing 20x30cm and manure application at transplanting with the same plant spacing resulted in the highest leaf size. This may be due to the combined effects of increased plant spacing and utilization of optimum nutrient balance for healthy and vigorous growth of the onion plant (Plate 4). To the contrary, onion plants grown on plots with no manure application showed the least leaf size. In these plots minimum plant population density and inappropriate manure application period were considered.

The combined effect of the treatments on the leaf size and infestation of onion thrips was studied in field condition. The total number of thrips larvae and adult obtained per plant also appeared significant among treatments at 60 and 75 days of the plant growth stages. These same treatments of manure application before transplanting and manure application at transplanting with plant spacing 20x30cm were observed having minimum mean thrips number in addition to their vigorous leaf growth. On the other hand, untreated plots especially with 20x20cm plant spacing were characterized by highest mean count of larvae and adults of *T. tabaci* and smallest leaf size.

The implication of this finding might be related to the impact of nutrient management, together with the influence of minimum plant population number. In these plots, it was observed deficiency of available nutrients and increased competition for the limited recourses from the increased plant density. On top of the impact of nutrient management, this result coincides with the evaluation of the effect of row-to row distance of onion plants on thrips population by Faheem *et al.*, (2003). They reported that minimum mean thrips number per plant was obtained with the largest row-to–row distance between onion plants.

Another lowest mean infestation was also recorded from the treatments with manure application at transplanting and 20x20cm followed by before planting manure application with 20x25cm plant spacing. This revealed that the application of slurry at transplanting might also elevate the soil nutrient available in addition to the exaggerated effect of wider line spacing on thrips population density.

Finally, the significant difference in the population density of the pest, in all the treatments, showed the direct and/or combined effect of line spacing and manure application.

The study on the effect of manure application and different plant spacing on the leaf damage due to onion thrips in field experiment, showed a significant variation at different growth stage of the plant. In most plants at 15 and 30 days after transplanting, treatments were observed having mild leaf damage except, with the untreated control that intermediate damages were recorded Onion thrips were first identified 15 days after transplanting most likely originated from the cultivated and wild alternate hosts in the field and around the border.

This mild attack was pertaining to the lower infestation level at early growth stage in most plants. On the other hand, sever and intermediate leaf damages at 45, 60 and 75 days after transplanting, characterized by the increased mean thrips number per plant in all treated and control check plants were due to the vulnerability of succulent onion plants to thrips feeding and increased leaf surface which provide protection.

The population density decreased as the crop was maturing but the damage was visible as sever and intermediate. This study is in line with the work of Yeshitla Merene (2005) who showed that 75 days after transplanting (eight leaf stage or visible bulbing growth stage) onion was observed to be vulnerable to thrips damage except at 45 and 60 days after transplanting showed also a significant increase in thrips number.

The finding by Arida *et al.*, (2002)coincides with my results in the present findings that thrips population similarly was low on onion at the start of the planting season and increased 60 days after transplanting. Workman and Martin (2002) indicted that at the final growth, stage of onion thrips number is reduced because of the decline in nutritional value of the onion leaves but the silvery patches of the previous attach appeared as there is high infestation at older stages.

The other reason for this sever and intermediate damage in most plants may be attributed to the over all thrips density of larvae and adults. The study area is located in arid region of the Gibe valley with minimum rainfall and the onion production system was based on drip irrigation considering the water shortage in to account. As a result, the mean population density of larvae exceeds the adult population that the damage was more severe. On the other view, this drip irrigation helped to reduce the water stress, which contributed to minimize the damage level. This finding agrees with the finding of Yeshitla Merene (2005) who showed that the overall thrips density is low in rain fed as compared to dried periods and the mean population density of larvae was higher than the adult population. This indicates that thrips damage is more serious in irrigated production system and thrips larvae are more injurious to onion.

The result on the average yield of onion grown on soil with organic manure and different plant spacing under field conditions revealed minor difference on the total bulb yield. In most of the cases, onion plants grown on soil with manure application before transplanting and wider plant spacing showed the highest yield. This result may also be related to the integrated impact of nutrient management and determining optimum plant population in these plots. On the other side, the lowest bulb yield was obtained from onion plants grown on soil with no manure application and wider spacing.

The survey on onion thrips host range revealed that *T. tabaci* was identified to feed on six cultivated and one wild plant species. Le Pelley (1959) reported that onion thrips was first observed in east Africa by Wilkinson (1937) on Pyrethrum (*Chrysanthemum cienereriifolium*) in Kenya. Later, *T. tabaci* was recorded on onions, and leeks. The study by Tsedeke Abate (1986) figured out these plants as potential alternate hosts for thrips in upper Awash.

The most important implication of this study in the management of onion thrips is that, cultural practices that enhanced the preventive aspect of the pest problem were applied. These agronomic practices included application of organic manure, onion plant spacing, field sanitation and drip irrigation.

The impact of these integrated cultural practices promoted the agro-ecosystem health that enabled the onion plant to tolerate some pest population. The onion plants that were healthy and vigorous tolerates onion thrips attack and gave optimum yield.

The system also encouraged the biodiversity in which predatory beneficial insects flourished, which might help reduce the pest population.

The study is supported by previous works such as Benbrook (1996) that, it is a system approach to pest management based on understanding of pest ecology. It begins with steps to accurately diagnose the nature and source of pest problems, and rely on a range of preventive tactics and biological control to keep pest population within acceptable limits. Norton and Mullen (1994) also described it as a system, which provide guidelines and options for effective management of pests and beneficial organisms in an ecological context.

6. CONCLUSIONS AND RECOMMENDATIONS

6.1 CONCLUSIONS

The findings of this study on combined effect of nutrient management and plant spacing on the infestation level of onion thrips emphasized that the lowest mean onion thrips infestation was obtained starting from 45 days after transplanting with manure application before transplanting at 20x30cm and 20x25cm plant spacing. These combinations also showed the highest yield with large bulb sizes.

This study illustrated that optimum organic manure applications at the appropriate time had effect on the infestation level of onion thrips. And manure application three months before transplanting was found to be the critical period for optimum plant growth with the lowest onion thrips mean infestation.

The population of onion thrips was observed to change with the change in the crop penology. The first population appeared 15 days after transplanting, which originated from the reservoir host in and around the field. The population is low at early growth stage, increased starting from 45 days after transplanting with the maximum 75 days after transplanting and decreased at the crop maturity.

The leaf damage depends on the total infestation and population density of onion thrips. It was indicated that variation in the population density of larvae and adults with the different combinations starting 30 days after transplanting. In most of the cases higher larval population was identified which made the damage more injurious.

It was observed that a significant difference in the leaf size among the combination of manure application and line spacing of onion plants. The highest leaf size deducted from manure application before transplanting with wider spacing. However, the number of leaves recorded per plant at the different phenological stages of the crop didn't differ with the treatments.

This study also emphasized on a new strategy of managing onion thrips. It integrated cultural practices and nutrient management to suppress the pest population and helped the crop withstand the damage to a certain level. The onion plants were healthy and vigorous that tolerates the thrips attack and gives optimum yield. It also encouraged the biodiversity that some predatory beneficial insects flourished and elevate the biological cycle, which created a healthy agro-system.

6.2 RECOMMENDATIONS

The following recommendations for effective management of onion thrips are forwarded based on the findings and observations made in the present study.

- ✓ Control of onion thrips is difficult due to its biology and behavior, therefore it is important to emphasize on its management.
- ✓ Proper monitoring and management decisions early in the growth stage help to reduce damage of onion thrips.
- ✓ Integrated organic onion thrips control methods reduce the over-reliance on the use of synthetic pesticides, which is associated with environmental disturbance, pesticide resistance and lethal and sub-lethal effects on non-target organisms including human.
- ✓ Farmers should integrate and use these practices and other integral methods to control onion thrips and produce organic onion.

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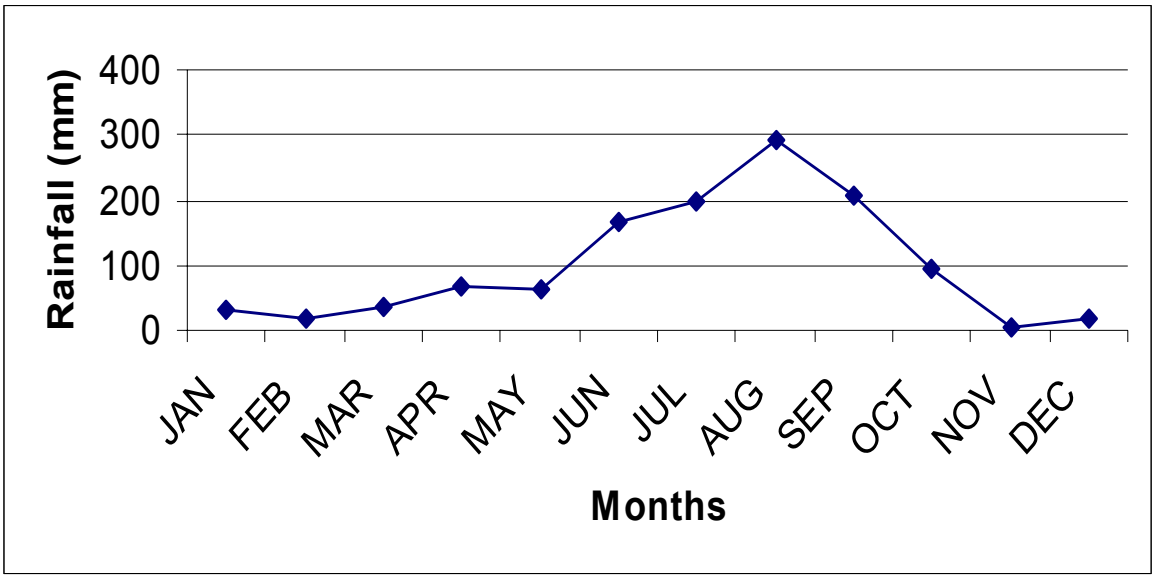
LIST OF PLATES

Plate 3. Healthy and vigorous onion plant with least onion infestation

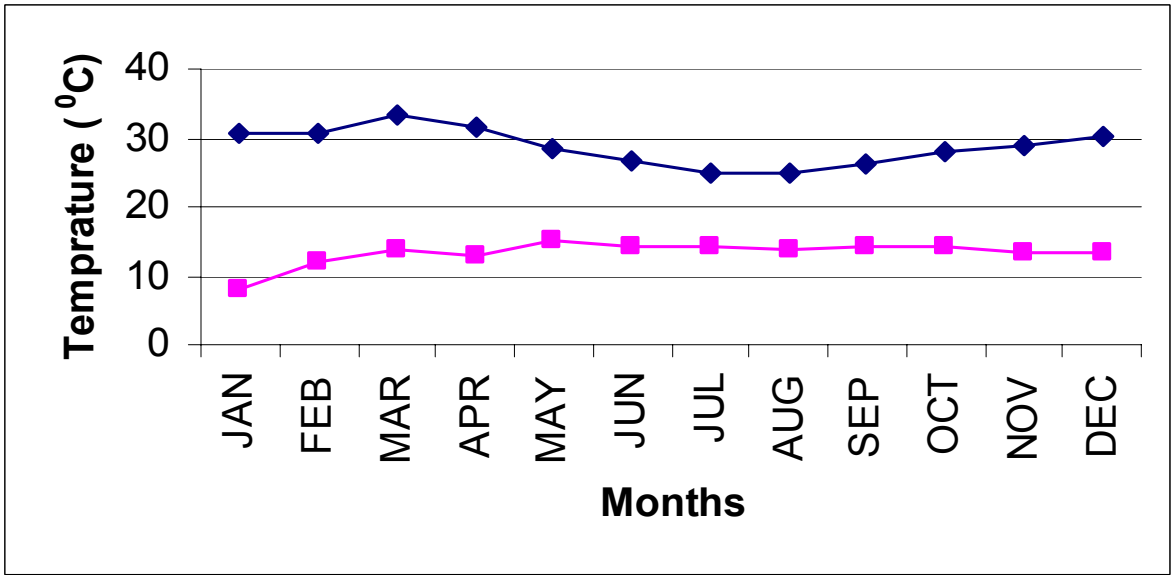
Plate 4. Healthy and vigorous onion plants on field

APPENDICES

Appendix 1. Monthly average rainfall of the Luke area



Appendix 2. Monthly maximum and minimum temperature of the Luke area



Appendix 3. Analysis of variance (ANOVA) for effect of manure application and plant spacing on the infestation level of *Thrips tabaci* at different stage of the crop

DAT	Life stage	source	Sum of squares	df	Mean square	F	Sig.
15 DAT	Adult	Between Groups	22.854	8	2.857	2.094	.092
		Within Groups	24.560	18	1.364		
	Larvae	Between Groups	3.294	8	.412	1.009	.463
		Within Groups	7.347	18	.408		
	Total	Between Groups	34.733	8	4.342	2.388	.060
		Within Groups	32.727	18	1.818		
30 DAT	Adult	Between Groups	117.113	8	14.639	2.531	.049
		Within Groups	104.123	18	5.785		
	Larvae	Between Groups	92.847	8	11.606	.580	.781
		Within Groups	359.931	18	19.996		
	Total	Between Groups	272.43	8	34.054	.772	.632
		Within Groups	793.807	18	44.100		
45 DAT	Adult	Between Groups	1660.221	8	207.528	3.299	.017
		Within Groups	1132.380	18	62.910		
	Larvae	Between Groups	6045.013	8	755.627	2.808	.033
		Within Groups	4844.002	18	269.111		
	Total	Between Groups	12673.76	8	1584.22	3.165	.020
		Within Groups	9010.762	18	500.598		

Continued appendix 3

60 DAT	Adult	Between Groups	670.427	8	83.803	2.859	.031
		Within Groups	527.680	18	29.316		
	Larvae	Between Groups	2605.867	8	325.733	6.443	.001
		Within Groups	910.080	18	50.560		
	Total	Between Groups	5207.707	8	650.963	5.26	.002
		Within Groups	2227.360	18	123.742		
75 DAT	Adult	Between Groups	341.781	8	42.723	5.390	.001
		Within Groups	142.667	18	7.926		
	Larvae	Between Groups	636.136	8	79.517	2.992	.025
		Within Groups	478.400	18	26.578		
	Total	Between Groups	1822.773	8	227.847	3.709	.010
		Within Groups	1105.653	18	61.425		
90 DAT	Adult	Between Groups	108.785	8	13.598	5.383	.001
		Within Groups	293.227	18	2.526		
	Larvae	Between Groups	353.493	8	44.187	6.108	.001
		Within Groups	130.213	18	7.234		
	Total	Between Groups	804.083	8	100.510	6.170	.001
		Within Groups	293.227	18	16.290		

Appendix 4. Analysis of variance (ANOVA) for Impact of Organic Manure application on Onion thrips population (cage Experiment)

DAT	source	Sum of squares	df	Mean square	F	Sig.
15 DAT	Between Groups	218.113	2	109.067	30.579	.000
	Within Groups	42.800	12	3.576		

Appendix 5. Analysis of variance (ANOVA) for effect of Manure application and different plant spacing on the size of Leaf at the different days after Transplanting (DAT)

DAT	source	Sum of squares	df	Mean square	F	Sig.
15 DAT	Between Groups	13.935	8	1.742	2.249	.073
	Within Groups	13.941	18	.774		
30 DAT	Between Groups	57.550	8	7.194	2.294	.068
	Within Groups	56.450	18	3.136		
45 DAT	Between Groups	549.610	8	68.701	17.11	.000
	Within Groups	72.267	18	4.015		
60 DAT	Between Groups	36.582	8	4.573	14.434	.000
	Within Groups	5.703	18	.317		
75 DAT	Between Groups	68.327	8	8.541	26.863	.000
	Within Groups	5.723	18	.318		
90 DAT	Between Groups	19.722	8	2.465	41.516	.000
	Within Groups	1.069	18	.059		

Appendix 6. Analysis of variance (ANOVA) for effect of Manure application and Different plant spacing on the number of Leaf at the different days after Transplanting (DAT)

DAT	source	Sum of squares	df	Mean square	F	Sig.
15 DAT	Between Groups	1.479	8	.185	2.495	.051
	Within Groups	1.333	18	.074		
30 DAT	Between Groups	5.6	8	.700	2.272	.071
	Within Groups	5.547	18	.308		
45 DAT	Between Groups	37.147	8	4.643	10.77	.000
	Within Groups	7.760	18	.431		
60 DAT	Between Groups	.190	8	.024	2.286	.069
	Within Groups	.187	18	.010		
75 DAT	Between Groups	.240	8	.030	1.558	.207
	Within Groups	.347	18	.019		
90 DAT	Between Groups	.027	8	.003	.578	.783
	Within Groups	.107	18	.006		

Appendix 7. Analysis of variance of data (ANOVA) on effect of treatments on Onion Yield

DAT	source	Sum of squares	df	Mean square	F	Sig.
15 DAT	Between Groups	12.689	8	1.586	37.63	.000
	Within Groups	.759	18	.042		

This thesis is my original work and has not been presented for a degree in any other university, and that all sources of material used for the thesis have been duly acknowledged.

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