BIOLOGY AND ECOLOGY OF *FRUMENTA NUNDINELLA* (ZELLER) (LEPIDOPTERA: GELECHIIDAE) AND ITS IMPACT ON HORSENETTLE (*SOLANUM CAROLINENSE* L.)

by

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INTRODUCTION

Horsenettle (*Solanum carolinense* L.) is a serious native weed in southeastern North America and is considered to be spreading northward and westward (Bradbury and Aldrich, 1957). It is an aggressive perennial which is highly competitive in pastures, cornfields, vegetable fields and orchards. It harbors many important insects and diseases of other members of the family Solanaceae which includes tomato, eggplant, potato, pepper, and tobacco. Applications of herbicides which are sufficient to control most weeds have little effect on horsenettle. As no work has been done on the possibilities for its biological control, it is a prime subject for preliminary biological control studies.

In 1972, under a grant from the Cooperative State Research Service, U.S.D.A., the Department of Entomology at V.P.I. & S.U. began a study of the insect fauna associated with certain weeds in Virginia, one of which was *Solanum carolinense*. In the summer of 1975 I began a study of this weed and the insects associated with it, with the objective of identifying and studying in detail the species which appeared to have the most potential as biological control agents of horsenettle. *Frumenta nundinella* (Zeller) emerged as the species warranting detailed treatment. The objectives were to determine the major phytophagous insect species associated with horsenettle in Virginia, and to study in detail the biology and life history of *Frumenta nundinella*, and its impact on horsenettle.

LITERATURE REVIEW

Solanum carolinense L.

Taxonomic Position. Horsenettle is a member of the family Solanaceae, notable for a number of alkaloid poisons and a large number of economically important plants, many of which are familiar in gardens (Rickett, 1966). According to Lawrence (1951) the genus Solanum comprises probably about 1,500 species, some of which are native to North America. Fernald (1950) stated that the family is largely tropical and only sparingly indigenous in the Northeastern U.S. He included six native and six introduced species of Solanum as persistent in the northeastern states. Close relatives of horsenettle include Solanum melongena (eggplant) and Solanum tuberosum (potato). Species from other genera in the family include Lycopersicum esculentum (tomato), Capsicum annuum (bell pepper), Nicotiana tabacum (tobacco) and Petunia sp.

Biology. Solanum carolinense was described by Fernald (1950) as a prickly perennial with a creeping, subterranean rhizome; stems simple or forking, hirsute with 4-8 rayed hairs, the slender prickles stramineous; leaves green, elliptic-oblong to oval, sinuate and coarsely toothed, scabrous; racemes several flowered, becoming one-sided; calyx lobes lance-acuminate; corolla violet or white in forma albiflorum Benke; anthers tapering to tip; berry yellow, naked, 1-1.5 cm in diameter. Bradbury and Aldrich (1957) found it to be very drought resistant and attributed this to the fleshy, penetrating roots which often reach the water table. They observed that horsenettle had a short growing season in New Jersey with new shoots seldom emerging before the middle of May and tops dying after the first frost in the fall. The plant grows rapidly during hot weather and blossoms and sets berries by the end of July. This is consistent with observations of the plant in Virginia.

Earlier they reported (1956) that the primary manner of propagation and spread of horsenettle was by root-stocks and rhizomes, contending that seeds played a minor part. Ilnicki et al. (1962), however, demonstrated a high percent emergence of seeds planted at depths up to 4 inches and good seed germination and seedling survival under field conditions. Both observations were probably correct, but it is likely that infestations originate from seeds in the field. Tillage operations will only spread the weed within an area or make it denser than before. They noted that root cuttings produced new plants when planted as deep as 18 inches in well drained, friable silt-loam soil. At 2 inches, 99% of the cuttings produced at least one plant.

Pest Status. Economic losses caused by this weed result from its vigorous competition with crop and forage plants. It is a host of several important plant diseases and insects (Somes 1916, Spencer and Strong 1926, Wallis 1951, Burdette 1935, Foott 1937b). Its spiny character also presents a problem in hand harvested crops as well as in forage crops (Furrer and Fertig 1961). Bradbury and Aldrich (1957) recognized it as a serious problem, particularly troublesome in crops such as alfalfa, corn, tomatoes, potatoes and orchards. Prichard and Porte (1921) demonstrated that horsenettle in tomato fields harbored *Septoria lycopersici*, the causative organism of leafspot of tomato. Several authors have cited horsenettle as an important alternate host of many pest insects (Somes 1916, Spencer and Strong 1926, Wallis 1951, Burdette 1935, Foott 1967). In southwest Virginia the weed is primarily a problem in cattle grazing areas and in cornfields where tillage tends to spread the rhizomes.

According to Bradbury and Aldrich (1957) horsenettle is a native of the gulf states and has spread northward and westward. It was reported as far west as California and as far north as Lake Erie. They indicated that it was listed as a primary noxious weed in 30 states, and was considered a serious and widespread weed pest, especially in the southeast, east and cornbelt states. In 1962 the weed was reported in Ontario (Foott 1963). Though references to S. carolinense are lacking from most regions, it has been introduced into Western Asia; by 1967 it was considered a pest worthy of attention in the Abkhazia of the U.S.S.R. (Todua and Stalyarnova 1967). The genus Solanum was considered to be a potential target for biocontrol in the U.S.S.R. by Kovalev (1968). New literature on solanaceous flora may reveal its presence in other parts of the world.

Attempts at Control. Horsenettle is not easily controlled by conventional means. Frequent clipping weakens the root system and reduces the stand somewhat over several years (Bradbury and Aldrich, 1957), but the weed remains a problem in frequently harvested forage crops such as alfalfa. Chemical control is considered unsatisfactory by several authors. Neville (1950) concluded that pre-emergence treatment with herbicides would not control horsenettle in corn. He indicated that a mixture of 2, 4-D and 2, 4, 5-T would kill growing horsenettle but was unclear as to its effect on the corn or how well the horsenettle recovered later in the season or in subsequent years.

For control in pastures, Albert (1960) found that the cumulative effect of three applications in four years of two pounds of 2, 4-D or 3 pounds of amitrole per acre greatly reduced the number of surviving plants. He added that the use of amitrole in pastures had not been cleared and that its higher cost along with less effective control of other weeds would severely restrict its usefulness. The 1978 Virginia Pest Management Guide (V.P.I. & S.U. Cooperative Extens. Serv. 1978) recommends two pounds each of 2, 4-D and 2, 4, 5-T in pastures at blooming time and indicates that all legumes will also be killed. The rate of application is much higher than necessary to kill most weeds. Recent increases in costs of herbicides and attention to hazards to man, animals and environment would make regular applications at such a high rate very inexpedient.

Suitability of Horsenettle for Biocontrol

The lack of formal studies on the biological control of horsenettle may be due to the generally poor acceptance of biological weed control in the past and to horsenettle not fitting the qualifications of a classical biocontrol target organism. The usual approach of searching in the region of origin for parasites for introduction into the area in which the weed is an alien pest is not applicable to a native weed. Although horsenettle is a native perennial weed, capable of reproducing in several ways, it is not necessarily unsuitable for biocontrol.

A perennial weed can be controlled by a foliage feeder which is well synchronized with the life cycle of the plant. By defoliating the plant throughout its growing season, it weakens the root reserves.

This was observed by Harris during studies of the cinnabar moth (*Tyria jacobaeae* L.) on the perennial tansy ragwort in Nova Scotia (oral communication, 1976). Though heat and drought favor horsenettle, vigorous interspecific competition in its southern range could be a very important factor in helping the parasites to bring about more complete control of the weed. Since the plant reproduces by seeds as well as by creeping rhizomes and root cuttings, a multifaceted approach to biocontrol would be desirable. Even if effective parasites of only one part of the plant are available (eg. seed feeders), it is possible that its reproductive capacity may be sufficiently restricted to reduce its competitive edge over the more desirable plants. A seed feeder could reduce the rate of spread of the weed by seed and still remain well established in the area on seeds produced by isolated patches of the weed coming back from roots year after year.

Kok (1974) stated four criteria for suitability of biocontrol for reducing the density of a weed: (a) single aggressive weeds, (since biological control is a selective process and cannot work against a complex of weeds), (b) alien weeds, (c) weeds not closely related to economic species, and (d) weeds of uncultivated land. For horsenettle the first criterion is easily met. This is an aggressive species and occurs in dense stands; a condition which allows for rapid multiplication of natural enemies (Frick, 1974). Any species which may take its place is not likely to be as undesirable. In southwest Virginia it is primarily a problem in uncultivated lands. It is expected that control agents that are successful in uncultivated areas would be able to extend their influence into crop areas. Though horsenettle is closely related to several economic species, there are some insect parasites attacking it that are quite host specific. This is perhaps due to the characteristic alkaloids produced by species in the genus Solanum (Hsiao, 1974).

Although alien weeds are generally the most suitable targets for biocontrol, there are circumstances for the application of the method to native weeds. Wilson (1964) cited the destruction of native chestnuts by the accidental introduction of a fungus, Endothia parasitica (Murrill), implying that intentional introductions against weeds could have the same effect. Pimentel (1963) suggested that native pests could be controlled by introductions of parasites and predators of related species and genera. He cited 27 successes in biocontrol including the prickly pear (Opuntia sp.) in Australia which, although an alien pest was controlled by parasites of a related species of Opuntia. His premise was that parasites and predators of related species, if adaptable, could establish much greater control than the natural parasites of the pest. He contended that the new parasite had not yet evolved a homeostasis with its new host by genetic feedback and could exert greater pressure than parasites which were closely evolved with the host.

Frick (1974) suggested that native weeds could be controlled by the conservation of native phytophagous insects; primarily involving a reduction in the numbers of native (hyper-) parasites, predators and diseases of the insects. He also suggested the periodic release and/or redistribution of natural enemies. He experimented with the mass culture of a native moth, Bactra verutana Zeller for inundative releases against the native yellow nutsedge and the introduced purple nutsedge. Debach (1964) generally agreed with this viewpoint in his discussion on "augmentation" and "conservation" of natural enemies. Conservation involved making the environment better suited to the natural enemy by reducing adverse conditions (humidity, tillage, non-selective pesticides) or by increasing favorable conditions (increasing wildflowers, alternate hosts). These concepts could probably be included under the general heading of integrated control, a method which may be very applicable to the horsenettle problem. Debach further stated that, although research on means of augmentation seems to strike a popular chord, it should in general be given the lowest priority in biological control research endeavours and not resorted to until it has been determined that the solution does not lie in foreign exploration and importation of new natural enemies or some type of conservation. The latter approaches can solve the problem permanently and often very cheaply (Debach, 1974). He also stated that augmentation attempts should usually be restricted to those natural enemies which have been demonstrated by research to be inherently effective in prey population regulation but are prevented from doing so principally because either they are not adequately adapted to weather extremes, are not synchronized with the necessary stage of the host or are otherwise rendered ineffective by periodic environmental unfavorability.

The preceeding statements help to point out the necessity for extensive ecological studies of the phytophagous fauna of a weed.

In the case of horsenettle, a study of its native insect fauna would be of value in the search for potential agents for control of the weed. A survey of the insect parasites of horsenettle and related weeds in other parts of the world would be of value for introductions in North America and vice versa. Harris (1971) suggested that the first step after determination of the weed's suitability for biocontrol should be a survey of the weed's parasites at home and abroad and that the parasites of greatest interest are those which affect parts of the plant that are lightly attacked in the problem area. Consistent with these theories, a thorough biological and ecological study of the more promising insects which attack horsenettle in southwestern Virginia is appropriate.

Frumenta nundinella (Zeller) (Lepidoptera: Gelechiidae)

Taxonomic Position. Frumenta nundinella was originally placed by P.C. Zeller (1873) in the genus Gelechia, a very large genus containing diverse species. Busck (1939) created the new genus Frumenta, referring to the genus Gelechia as a wastebasket for hundreds of heterogeneous species that could not be readily assigned to other genera. Frumenta contains only a single species and is considered closely related to the genus Gnorimoschema based on characters of the palpi, scaling, and aedeagus. The latter genus contains the well-known solidago gall moth (G. gallaesolidaginis (Riley)) which was originally described by Riley (1869) as a Gelechia species. Other well-known members of the family which are useful for comparisons are the Angoumois grain moth (Sitotroga cerealella (Oliv.)), which has habits similar to F. nundinella; the pink bollworm (Pectinophora gossypiella (Saunders)), an important pest of cotton; the potato tuber worm (Phthorimoea operculella (Zeller)); and Stomopteryx palpilineela (Chambers), a leafminer and leaftier of crownvetch (Valley and Wheeler 1976). All of the aforementioned species are fairly host specific and are well adapted to their hosts.

Distribution. The insect was originally described from Texas (Zeller 1873) and is distributed throughout the south. Specimens are recorded from Arkansas, Georgia, Illinois, Indiana, Missouri, Pennsylvania, and Virginia (U.S. National Museum collection) and has been reported from Ontario, Canada (Foott 1967a). Its distribution probably coincides with that of horsenettle in North America.

Biology. Murtfeldt (1881), believing that she was describing a new species, called the insect Gelechia beneficentella. She noted that the first brood larvae could be found early in May folding the terminal leaves of S. carolinense into round, hollow balls, each forming the habitation of a single larva which feeds on the incipient flower buds and the infolded edges of the tender leaves. She noted that the pupa was suspended in a mass of fine webby matter produced by the mature larva and that an opening was prepared for the exit of the mature moth within two weeks. She mentioned that a second brood followed but gave no details. Montgomery (1933), studying insect parasites in Indiana, noted that the larvae of Gelechia nundinella Zeller were found in gall-like capsules formed of thickened and fused terminal leaves of S. carolinense in June and in the fruit of the same plant in the latter half of July and throughout August. Parasites which emerged from larvae in fruit included: Spilocalcis sp., Microbracon mellitor (Say), Microbracon n. sp.

and Eurytoma bolteri Riley, the latter having been recorded from G. gallaesolidaginis Riley. Foott (1967a) found larvae of F. nundinella (Zeller) in horsenettle fruits in Ontario, Canada throughout August and noted that the larvae consumed the interior of the fruits and that mature larvae excavated small circular holes in the wall of the fruits prior to pupation, leaving a thin membrane covering the opening which was easily ruptured to permit the escape of the adult. He found only one individual per fruit.

All of the previous workers have indicated S. carolinense as the only host for F. nundinella and no other hosts are known to be recorded in collections. Detailed life history studies and evaluations of this insect's ability to damage horsenettle have not yet been carried out.

Other Insects Associated with Horsenettle

Literature on insects associated with horsenettle consists mostly of references to horsenettle as an alternate host for pest insects though there are some references to less well-known insects. Somes (1916) studied several horsenettle insects in Missouri which he thought had potential as pests of related plants. He reported a berytid bug, Jalysus spinosus Say, which he considered to be an important potential pest of tomatoes. This species has since been recognized as an important predator of aphids and lepidoptera eggs in tobacco fields (Elsey and Stinner 1971). He found larvae of Sesia rileyana Dry. in the stems in spring and adults of the same species in August and indicated that this moth transferred easily to potato and tomato but did not mention development to maturity. The tortoise beetle Nuzonia (Cassida) pallidula (Boh.)

was common and completed its development on both potato and tomato. The lace bug Gargarphia solani Heid, which has been called the "eggplant lace bug" was abundant and fed readily on tomato leaves. The potato stalk borer Trichobaris trinotata Say and the flea beetles Epitrix fuscula Crotch and E. cucummeris Harr. were numerous on horsenettle. Three other insects mentioned in this study were the sphingids Phlegethontius carolina L. and P. quinquemaculata Haus. and a lygaeid bug Ischnodemus fallicus Say.

Spencer and Strong (1926), reporting on the potato tuberworm, Phthorimoea operculella Zeller, indicated that it will infest horsenettle to a minor extent but prefers other solanaceous plants.

Wallis (1951) named horsenettle as one of 23 solanaceous host plants of the potato psyllid, Paratrioza cockerelli (Suk.) in Nebraska. Rolston et al. (1965) reported that horsenettle is the usual source of infestation for the eggplant tortoise beetle, Nuzonia pallidula (Boh.)

Hsaio (1974) listed three species of Leptinotarsa which would feed on horsenettle to some extent. The Colorado potato beetle, L. decemlineata, and another species, L. texana, developed moderately well on horsenettle, whereas L. juncta developed optimally. L. juncta also developed on the weed Solanum dulcamara and moderately on leaves of eggplant, S. melongena.

Burdette (1935) described horsenettle as an important alternate host for the pepper maggot, Zonosemata electa Say and suggested that the maggots were abundant everywhere that horsenettle was found fruiting in New Jersey. He said that the adults showed no particular preference for either the horsenettle berries or the peppers.

Foott (1976b) observed several insects feeding on horsenettle during a study of the pepper maggot in Ontario, Canada. Included were Colorado potato beetles, flea beetles, the potato stalk borer, as well as larvae of *Frumenta nundinella*.

MATERIALS AND METHODS

Study Sites. All studies were carried out in open pasture or pasture-like environments. Initially, collections were from pasture, cornfield margins, and waste areas from throughout Montgomery county and Giles county, Virginia. Distribution surveys were conducted in connection with thistle insect surveys throughout Western Virginia each June, and the field life history studies were conducted near Prices Fork in Montgomery County. For the latter, a 30 m^2 area with moderate infestation of horsenettle was cordoned off and was not mowed or sprayed with pesticides but was treated once with hydrated lime during the study period.

Host Propagation. Host material was grown by several methods. Throughout the summer, rhizomatous root cuttings 7-12 cm long were brought in from the field and planted 5 cm or more deep in flats or pots and allowed to sprout. According to Furrer and Fertig (1961) this is a reliable method of producing new plants, and is the best method to produce large, healthy plants quickly. In the fall, root cutting germination was sharply reduced, and seeds from ripe berries were used. Good germination was obtained by sprinkling dried seeds directly on moist soil surfaces in pots or flats, covering with 2-3 mm of fine soil, and covering with polyethylene bags until germination which normally occurred in about one week. By this method, it took approximately two months to produce usable plants about 20-30 cm high under greenhouse conditions in winter. Vegetable plants (tomato, pepper, eggplant), for host specificity studies were propagated in a similar manner. Potato plants were produced from cut tubers planted about 5 cm deep in pots.

When necessary, horsenettle and vegetable plants were brought in from fields and gardens and transplanted to pots.

Plants were almost exclusively grown in 15 cm dia. pots containing Weblite Soiless Potting Mix®. A teaspoon of lime and a teaspoon of Osmocote® 14-14-14 fertilizer were added. A small amount of Miracle-gro® liquid fertilizer was used in the first watering to add trace minerals. Plants were grown in the greenhouse during the winter and were placed outdoors during the warm months to avoid greenhouse pests. Whiteflies, mites, and aphids were a constant problem. Generally, the only way to stay ahead of them was to continually grow new material. Pesticidal sprays were occasionally used but only when sufficient time could be anticipated before using the plants with the insects.

Plants for field cage studies were either transplanted from material grown in the greenhouse or in the field, or caged at their original field location.

Distribution and Abundance. In the late summer of 1975 a field survey was carried out to establish the identity of a lepidopterous larva which had been previously encountered in the berries of horsenettle. This survey was also designed to get some working information about abundance, length of life stages, preference for oviposition, and peak periods of emergence.

From 20 to 40 berries per week were enclosed in small screenwire cages at each of two sites (Giles County and Montgomery County). Two to 10 berries were enclosed per cage while still attached to the plant. This was done weekly for 9 weeks from July 29 to Sept. 23.

Cages were checked each week for signs of infestation or for emerged adults or parasites. At the same time, large numbers of berries were collected from throughout the Giles-Montgomery area and dissected in the laboratory or held for emergence of adults.

In the succeeding seasons it was easy to detect infested berries in the field due to their characteristic external appearance or the presence of an emergence membrane on the side. In early summer, the characteristic leaf chambers containing larvae or pupae are easily recognized. Such specimens were either collected in polyethylene bags, brought in as whole potted plants, or observed directly in the field. Moths were allowed to emerge in bags but frequently the leaf chambers would rot before emergence. It was found that bringing in live plants and placing small bags over the chambers was more effective in reducing mortality. Berries were more resistant to rot than leaf chambers and could be removed from the plant without affecting emergence if the insect had already pupated. In all cases information on location, date of collection, stage, and parasites was recorded. For county distribution records, signs of previous infestations were noted and observations of living specimens were recorded.

In 1976, a vegetation survey was made in Giles County to document the change in coverage of horsenettle through the summer compared to other herbs, legumes, and grasses. The intention was also to record changes in population levels of F. nundinella in the sample area. The method was one using random quadrats and cover classes after that of Daubernmire (Mueller-Dombois and Ellenberg 1974). Ten percent of two 40' x 40' plots (one grazed and one ungrazed) were sampled each time on June 7, July 7, and August 7 of 1976.

Overwintering Stage. Three methods were used to discover how the insect overwinters. In the fall of 1975 adult moths which emerged from berries were released into a 60 x 60 x 60 cm envinromental chamber which contained potted horsenettle plants. Temperature and photoperiod were maintained similar to outdoor conditions for that time of year (12^{o}C, 12.5 hr. photoperiod). Moths were observed daily; dates of release and death were recorded.

In the fall of 1976 two other methods were attempted. Infested plants in the field were covered by wire cages which consisted of wire screen folded over and stapled along the edges. The bottom end was left open and was supported by a heavy wire hoop. The hoop was entrenched and staked to the ground around the plant, then packed with soil so that there was little chance of escape for the moths. In some cases extra berries containing pupae were added to the cage before sealing the base. The plants and berries were observed regularly until frost to determine what stage the insects had entered by winter.

The second method consisted of using two wood frame cages, 60 x 60 x 60 cm (Fig. 1) located at Prices Fork. They were covered with wire screen and organdy on 6 sides to reduce chances of escape of the moths. A glass jar was cemented over a hole in the top to collect moths attracted by light. The cages were sunk about 25 cm into the soil with the hinged door facing upward, and then filled to soil level with sifted Weblite Soiless Potting Mix ^{R} . Plants of various sizes, with and without berries were transplanted into the cages to create a somewhat natural environment. Planting at soil level provided the insects the natural temperature regulating effects of the earth during the cold months. Six berries

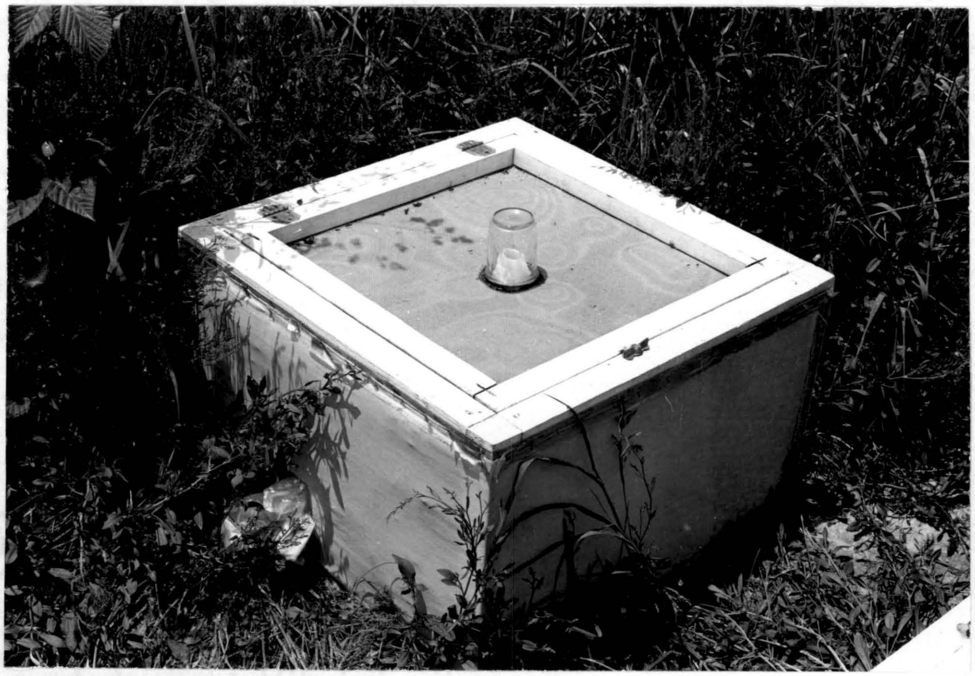

Fig. 1 Overwintering cage used for F. nundinella at Prices Fork. Bottom edges of the cage were buried ca 25 cm in the soil.

with pupae were placed in each cage by way of the door on August 13, and 15 more were added to each on Sept. 12.

The folded wire cages were examined in the month of December. All above ground parts were dissected and examined under a stereo scope. Soil arthropods were extracted from the soil down to 15 cm below the surface enclosed by the cages. Extracted arthropods were examined under a stereoscope for any stage of F. nundinella.

The method of extraction was to loosen and break up soil in a bucket of water, removing large masses of soil-free roots and grass. The water was then saturated with sugar or salt and stirred well. As the soil settled, animal and organic matter floated to the top. Surface material was skimmed off and worked through #14 and #10 Standard sieves. Material was worked to the corner of each sieve and transferred into 70% ETOH to be examined later.

The material in one of the two wood-frame cages at Prices Fork was examined in the same manner down to 15 cm below the surface. This was done on March 4, 1977 and was a simpler process because of the sifted soil used in the cage. The remaining cage was observed regularly until the beginning of the growing season.

Life history. Since the insect remained hidden throughout the larval stage, the number of larval instars and head capsule size of each instar were determined by examining the contents of infested berries for cast head capsules, measuring them and applying Dyer's law to make the complete sequence. Such observations could not be made directly on living larvae in the field because live specimens were not abundant and were not recognizable until the larva had reached a late instar.

During the summer of 1977, a vigorous colony of *Frumenta nundinella* was established in the remaining cage of the overwintering studies at Prices Fork. The colony resulted from overwintering insects that were released in the cage the previous fall and was of sufficient density to study its field life history and to conduct tests. Regular observations were made to determine initial symptoms of infestation and to trace the insect's development throughout its life. Twenty-five emerging plants were marked by plastic pot markers near their bases. The number of leaf chambers and the date of first appearance of each chamber was recorded for each plant. Initial observation was on May 27. Subsequently, the plants were visited at 2-4 day intervals to record dates of (1) appearance of new chambers (2) pupation (i.e. appearance of an emergence window) and (3) emergence of adults (broken emergence windows). The compiled data was used to determine the length of the larval and pupal stages and to provide part of the information for the phenology chart.

Pupae not used in the above study were taken into the laboratory and allowed to emerge as adults into a 30 x 30 x 50 cm plexiglas sleeve cage (Fig. 2). The transparent cage facilitated observation of the moths. Longevity of the adults, fecundity and egg laying habits of the females were noted. Eggs were obtained for descriptive and biological studies. A total of 15 pupae (in leaf chambers) was placed in a petri dish on the floor of the chamber. Four cuttings of horsenettle in vials of water were placed in the cage. A potted thistle plant was placed in the center to help maintain humidity at a level favorable to the cuttings and the insects. Data taken each day included: (1) number

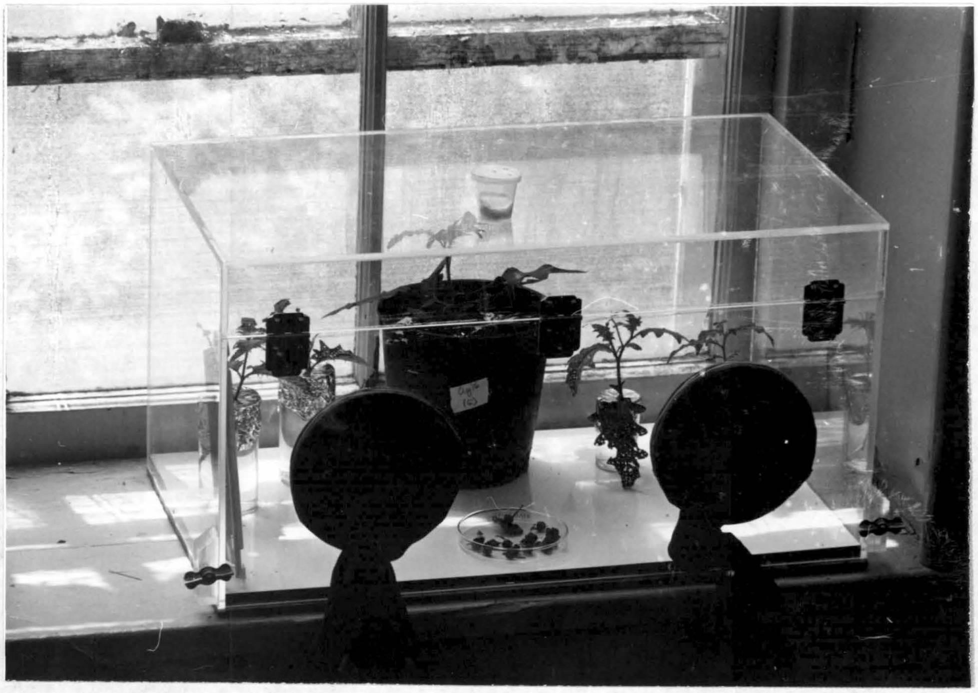

Fig. 2 Plexiglas sleeve cage for maintaining adults of F. nundinella.

of moths emerging that day, (2) number alive in the cage, and (3) number and sex of dead moths.

At 2-4 day intervals, the horsenettle cuttings were replaced and examined for eggs. The total number of eggs for the period was recorded each time. The eggs were removed with a brush, placed on moist filter paper in a 4 cm dia. plastic jelly cup and held at 24°C. Eggs were allowed to hatch in the cups and the hatching dates were recorded. Newly hatched 1st instars and some eggs were used for host specificity testing.

The phenology of the species in Virginia was worked out from a combination of field and laboratory data recorded over three years. The dates were plotted on the phenology chart and then extrapolated to a point based on the estimated length of the life stages.

Impact on Horsenettle. The infested plants in one of the overwintering cages were also used to determine the impact of 1st generation larvae on growth and development of the plants in terms of dry weight.

Adjacent to the overwintering cages, control plants also from rootstocks of the previous season, were grown in identical cages.

Twenty-two control plants were marked with plastic pot markers. On July 23, 1977 after the 1st generation adults had emerged, the control plants and the 19 plants which had been attacked by one or more larvae were clipped at the base, tagged and put in separate plastic bags. They were taken to the laboratory and placed on the open shelves of a drying oven for 4 days. The dry weight of each plant was recorded. A comparison was made between more larvae using Statistical Analysis System (SAS) General Linear Models procedure (proc GLM) followed by Duncan's multiple range test.

Host Specificity. In the middle of July, 1976, three 60 x 60 x 60 cm screen wire cages were set up just outside the greenhouse with different potted plants as follows: (a) 4 solanaceous crop plants (tomato, potato, eggplant and pepper); (b) the same 4 solanaceous crop plants and horsenettle; and (c) 2 plants of horsenettle with berries and 2 without. First generation adult moths which emerged from leaf chambers of plants brought in from the field were sexed and released in pairs into the cages via holes in the top. One month later the plants were dissected and examined carefully under a stereo scope for signs of the second generation.

During the summer of 1977 potted plants of tomato, eggplant and pepper were placed in a field cage which contained a thriving colony of 1st generation *F. nundinella* larvae within leaf chambers of horsenettle plants. When oviposition pressure from emerging adults was high the plants were replaced weekly and examined carefully for eggs. Simultaneously, eggs and first instars arising from the adults in the plexiglas sleeve cage were innoculated on to a potted pepper plant grown in the laboratory. A camel's hair brush was used to place eggs and larvae on tender leaves and growth tips to see if they could establish themselves.

Other Insects Associated with Horsenettle:

Horsenettle plants from various locations in Southwest Virginia were uprooted in the field and quickly inserted into polyethylene bags. Plant material was brought to the laboratory and separated into root, stem and leaf categories. Sorted material was kept in bags that were hung from a line. The openings of the bags were spread open by plastic cups, the bottoms of which were replaced by wire mesh to allow air circulation in the bag. Insects were collected as they appeared in the bags. They were identified and note was made of the plant portion from which they came.

Field observations were made on insects which fed on the plant or otherwise caused damage. Insects which were observed feeding were collected and preserved in 70% ETOH or dry mounted on pins. Some were kept alive on plant material in the laboratory for behavioral observation or parasite emergence.

One insect, Leptinotarsa juncta, was tested for ovipositional preference. Six females and four males were released into a sleeve cage containing 2 potted plants, one each of horsenettle and eggplant. A layer of cardboard with two 10 cm dia. holes, one for each of the plants to go through, was inserted horizontally at the level of the leaves. The females had easy access to either plant. Beetles were released from a point at the center of the cardboard. For each of six consecutive days, adults were gathered from the leaves before egg counts and removal from each plant. Adults were again released in the center after each counting.

To assess the damage done by larvae of L. juncta, 1st instars were released into 6 field cages (60 x 60 x 60 cm), each containing 4 horsenettle seedlings. The first instars were obtained from eggs laid by wild females on leaves of horsenettle and hatched on moist filter paper in petri dishes. A total of 60 first instars were released on leaves of plants 15-20 cm tall at rates of 0 (control), 4, 8, 12, 16, and 20 larvae/cage. Daily observations on feeding and development were carried out until pupation.

RESULTS AND DISCUSSION

Frumenta nundinella (Zeller)

Distribution and Abundance. F. nundinella was not abundant in Southwestern Virginia. Moths were often difficult to obtain and local distribution appeared to be spotty. Most areas of heavy horsenettle infestation failed to produce specimens; those located were found only after a thorough search of areas known to harbor them in the past. This required familiarity with the habits of the insect and symptoms of infested hosts.

Survey attempts did not yield sufficient numbers to quantify the population levels of F. nundinella. Table 1 is a summary of the survey using caged berries conducted in late summer of 1975 in Montgomery and Giles Co. The survey began when berries were first forming in late July and was continued until frost. Of 522 caged berries, only 8 (2%) produced adult F. nundinella. Besides indicating that the population level was low in the area, the survey also provided specimens for study and gave some insight into the life history and behavior of the insect for use in designing future studies. All the moths emerged between Sept. 16 and Sept. 30.

Fig. 3 shows the results of the vegetation survey made in 1976 based on a random quadrat method to determine % coverage. The data indicated a slight increase in horsenettle relative to other pasture plants as the summer progressed. There was apparently little difference in coverage of horsenettle between the grazed and ungrazed areas for the short term. This might indicate that cattle were avoiding the horsenettle and were having no direct effect on its growth. It is

Table 1. F. nundinella adults recovered from caged berries in Giles and Montgomery Co., Summer 1975.

	Date of Caging								
	Jul 29	Aug 5	10	19	26	Sept 2	9	16	23
Number of berries caged	60	60	60	60	60	60	51	50	61
Number of infested:									
Montgomery Co.	0	1	0	0	3	0	0	0	0
Giles Co.	0	0	0	0	1	0	0	3	0
Moth emergence		Sept 23			Sept 16 23 30(2)			Sept 16 23(2)	

Total berries caged = 522

Total infested with F. nundinella = 8

% infestation = 2%

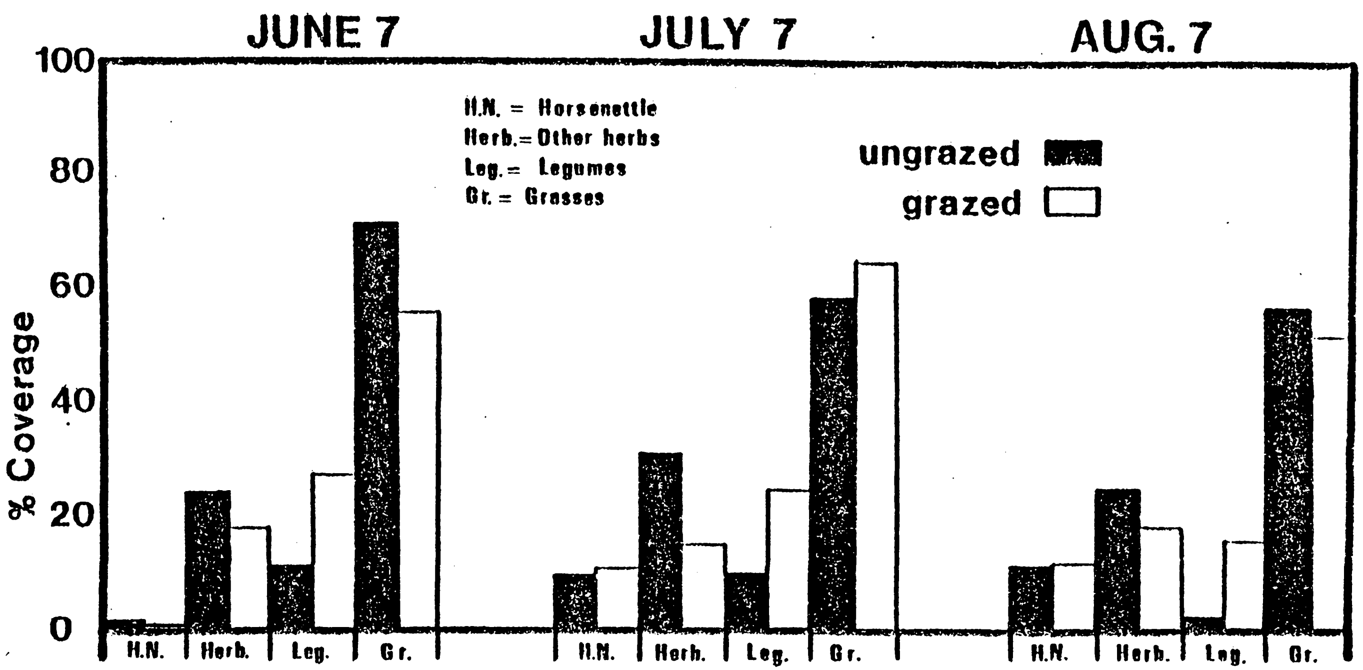

Fig. 3. Change in % coverage of horsenettle compared to herbs, legumes, and grasses through the summer of 1976.

reasonable to assume, though, that over the years, the indirect effect of continually removing competing plants from around the horsenettle would tend to increase its coverage to exceed that in the ungrazed area. F. nundinella was encountered in only one quadrat on Aug. 7.

The observed distribution of F. nundinella in Virginia is shown in Fig. 4. Black dots indicate counties in which at least one adult, larva or pupa was observed or evidence of past infestation was found. In all counties but Montgomery and Giles, less than 10 individuals were detected. This data was based on observations made during insect surveys of the western counties each June of 1975, 76, and 77. It is probable that the insect occurs in most of the counties of similar environment in the mountain and valley regions of Virginia (western counties), and may be locally abundant in some areas. Although horsenettle is known to be abundant in the eastern half of the state, I am not aware of the occurrence of the insect in the Piedmont and Tidewater regions of Virginia.

Overwintering stage. Results indicate that F. nundinella overwinters as the adult. Its closest relative, Gnorimoschema gallaesoladaginis Riley, overwinters as the adult (Riley, 1869) and some other Gelechiids (potato tuberworm, Angomois grain moth) also overwinter as the adult under certain conditions. Emergent moths of F. nundinella which were released into environmental chambers in the fall of 1975 became motionless after 2-3 days. No eggs or larvae were found on the plants in the chamber. All of the field infested berries collected at that time yielded adults that emerged or had immature stages that died from parasitism or disease. Thus adults were the only viable form during

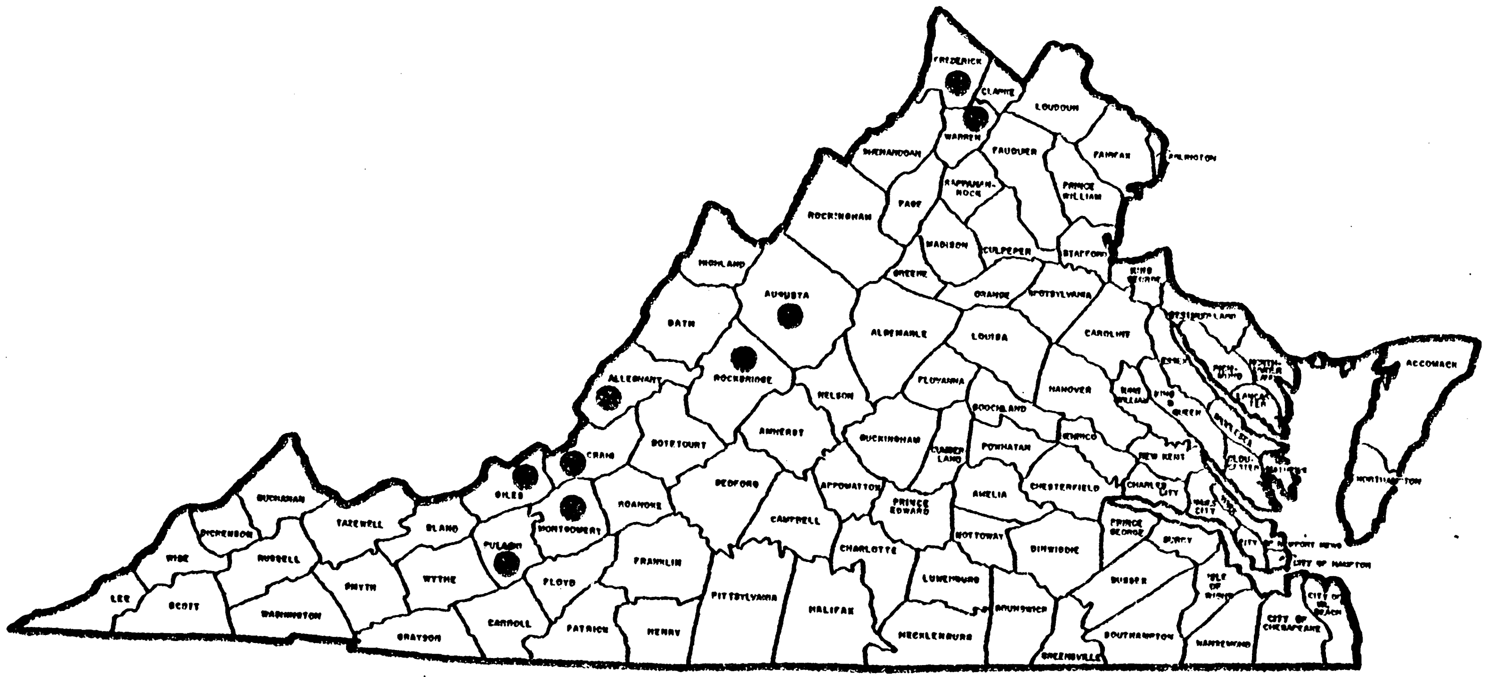

Fig. 4. Counties in which evidence of F. nundinella was observed or collected.

the fall.

In the 1976 overwintering cages, every insect had either emerged or died by the time they were examined between December and early March. Careful dissection and examination of the plant parts revealed no eggs or immature stages. Six adults of the 21 pupae caged were found dead on the soil surface. Extraction of the soil by the described method produced larvae and pupae of other species but none of F. nundinella. Viable overwintering adults were apparently well hidden in crevices. The sunken cage at Prices Fork that was left untouched during the winter had larvae infesting the tips of newly emergent shoots of horsenettle by May 28. Extrapolating from later stages, females lay eggs on horsenettle shoots between early May and mid-June (Fig. 5). Thus the 1st generation was from eggs laid by overwintered females.

Life History. The insect has 2 generations per year in western Virginia (Fig. 5). Under normal circumstances, the first generation larvae occupy leaf chambers at the growth tips of the plant and the second generation larvae occupy the interiors of horsenettle berries (Fig. 6). The insect is well adapted to the life cycle of its host. Overwintered females begin laying eggs just as horsenettle shoots begin to appear (mid to late May) and continue until mid-June. Females oviposit on the sides and tips of emerging shoots and later on new growth and undersides of leaves of established plants. Most eggs are concentrated on young stems near leaf joints. Freshly laid eggs adhere readily to the plant surface due to a sticky substance on the egg surface.

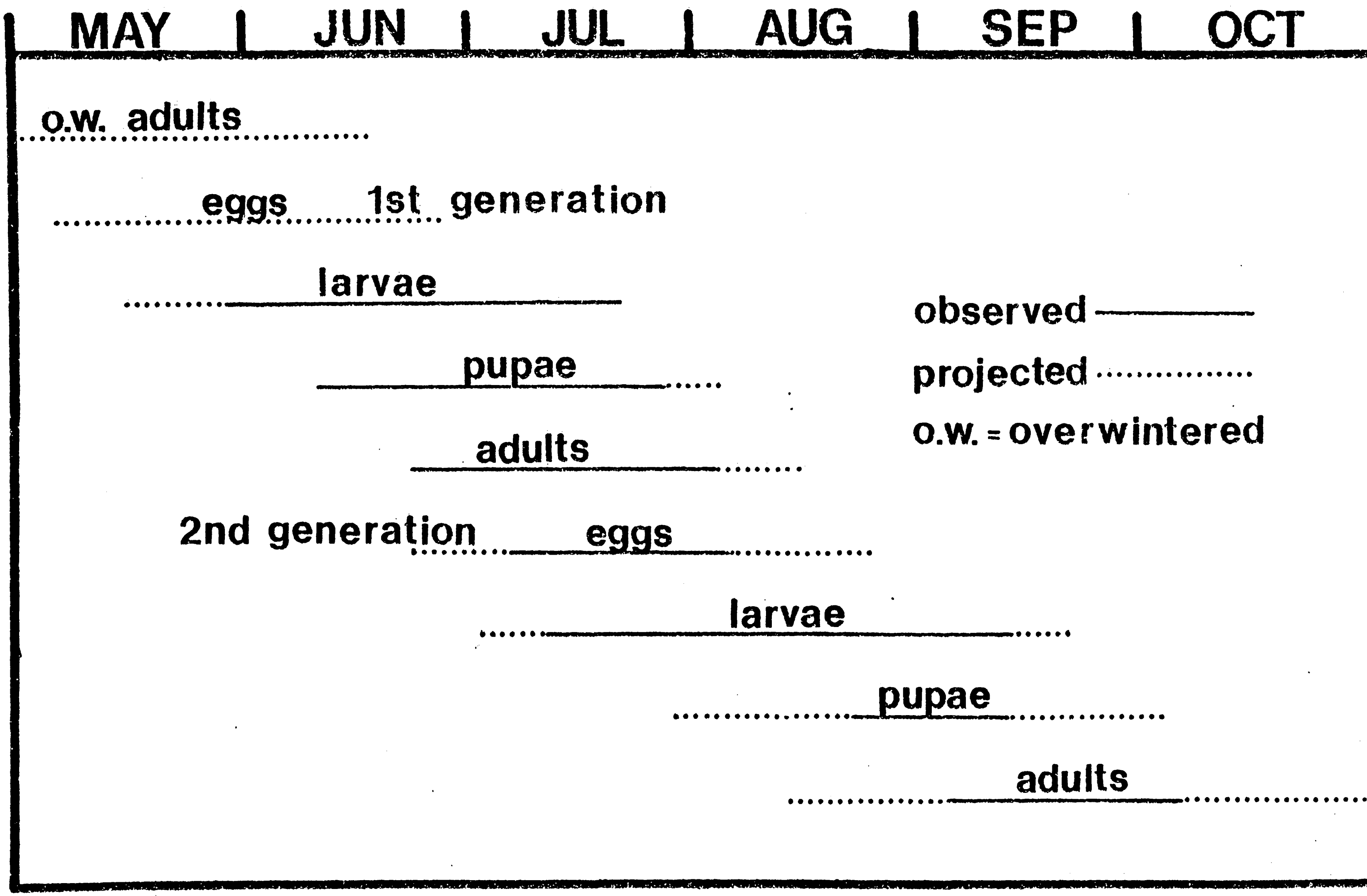

Fig. 5. Phenology of *F. nundinella*

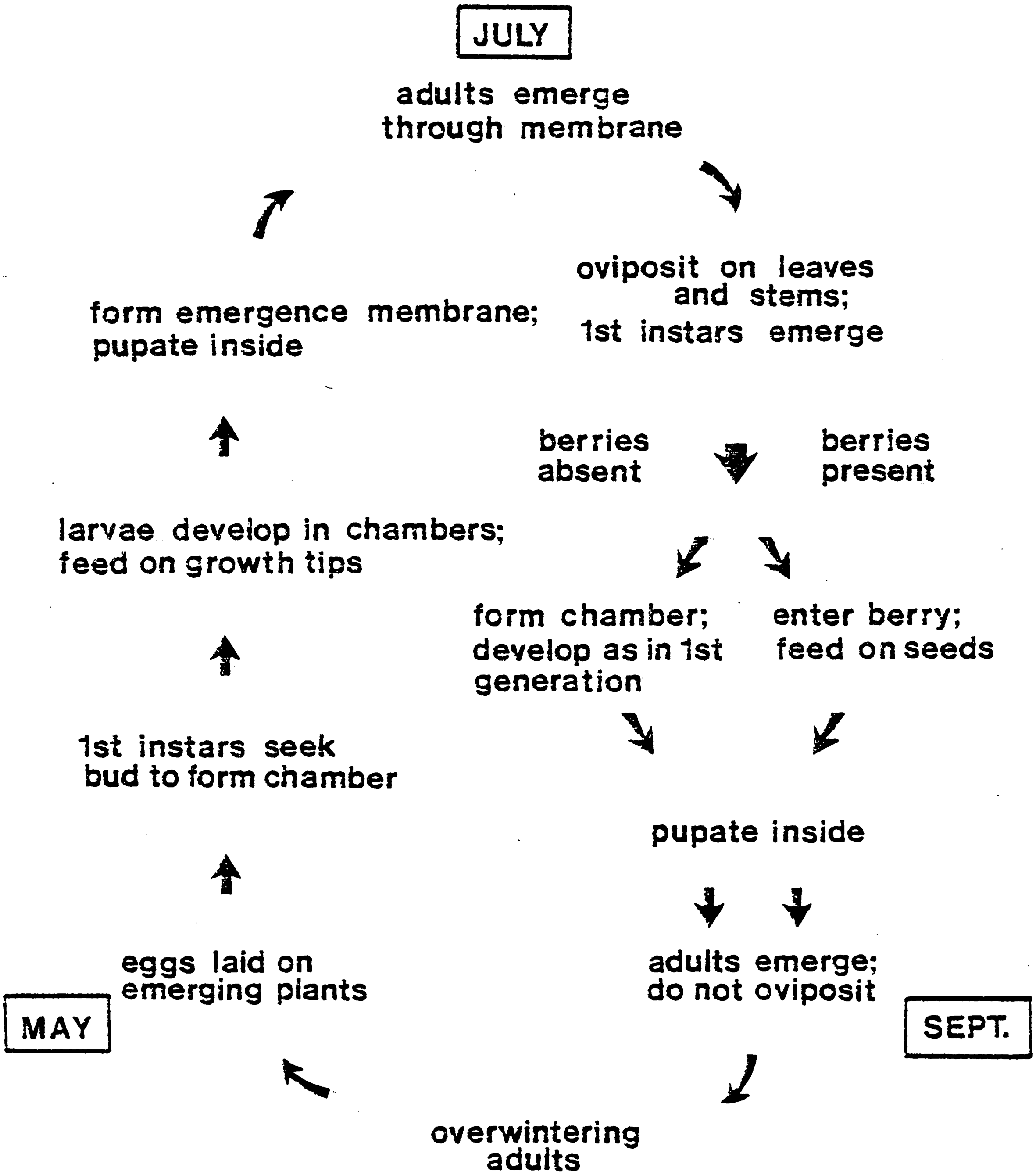

Fig. 6. Summary of life cycle of F. nundinella.

and the presence of tiny spicules all over the surface of the plant. The eggs are typical lepidoptera eggs, .43 mm x .2 mm and heavily sculptured (Fig. 7). They are initially pale yellow but change progressively to an orange-red. Near the end of the incubation period (average 11.5 days) one end of the egg becomes black due to the darkening head capsule.

On hatching, the first instar pushes open an operculum on the flat end of the egg and crawls out. It is almost microscopic with head capsule width of 0.2 mm and length 10 mm. The newly eclosed first instar wanders on leaf and stem surfaces (Fig. 8) until it reaches a leaf bud either at the apical growth point or at a leaf joint. It then feeds at the tip of the developing bud. As the leaves grow, the larva encloses itself in a leaf chamber by webbing the young leaves together at their edges. This is done very neatly with all edges well sealed and no webbing visible from outside the chamber. The chamber is oblong and approximately 1 mm x 2 mm when first formed (Fig. 9). By this time the larva had reached 2nd instar.

The first instar is the only time in the insect's larval stage which is unprotected. It is very vulnerable to predation and harsh elements and the majority probably do not survive. The first instar has to make its way from egg to chamber in a very short time (1-2 days) or it will die from dessication. Many are swept off by wind or rain, wander in the wrong direction, or fail to find suitable sites due to intraspecific competition. The latter was frequently observed in the laboratory because of crowding but is unlikely to be an important factor in the field where host plants are abundant. Interspecific competition

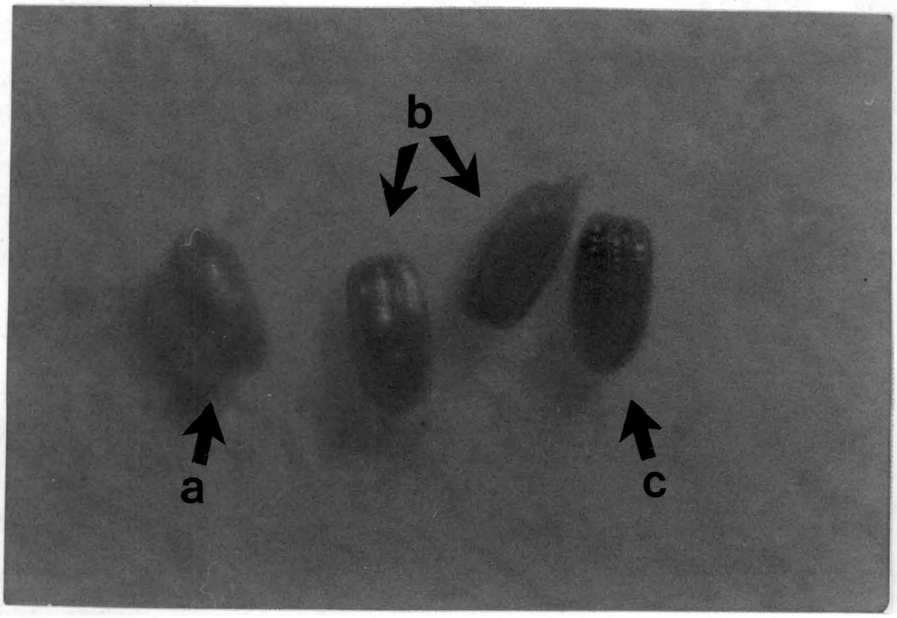

Fig. 7. Eggs of F. nundinella in progressive stages of development (a) freshly laid, (b) 2-9 days old, (c) 10-12 days old.

Fig. 8. First instar of F. nundinella on underside of leaf.

Fig. 9. Horsenettle shoot with newly developed leaf chamber formed by F. nundinella larva.

Fig. 10. Fully formed leaf chamber resulting from infestation by F. nundinella larva; note eggs at base.

from common insects such as flea beetles is important as they create irregular surfaces and make it difficult for the first instar to reach the bud. Several first instars were observed to keep themselves covered by a tunnel of webbing as they moved down the stem or leaf. Others fed as they moved and left a groove in the surface tissue along the path to their chambers.

Once the chamber is formed (Fig. 10) the larva remains inside, protected from most predators and parasites, until emergence as an adult moth. The larva always occupies the chamber alone. In some chambers a dead first instar was found along with a living later instar, indicating that the former may have died competing for the site. Two or more larvae are apparently not capable of co-existing inside a single chamber.

The larva feeds, head downward, on the growth tip of the plant inside the chamber. As it feeds, frass accumulates only at the top of the chamber. The growth tip, and the leaves which form the chamber become thickened and fused as if there was some chemical influence from the larva, as with a gall insect. The chamber grows with the larva and becomes roughly spherical. If the larva dies, the chamber often splits open and the growth tip leafs out and grows normally. Throughout the larval stage the integrity of the chamber appears to be maintained by this larval influence as well as by webbing attachments along the seams.

The larva passes through 6 instars within the chamber. The last is roughly 1 cm long with a head capsule width of .96 mm (Table 2). By the time the larva reaches the 6 th instar, the chamber is 1-3 cm in diameter. The plant bearing the chamber has a poor physical

Table 2. Measured dimensions of egg, larva and pupa of _F_. _nundinella_.

Measurement	No. Obs.	Mean (mm)	Standard Error	Range
Egg				
Length	11	0.43	0.001	0.43-0.45
Width	11	0.22	0.001	0.20-0.23
Larval head capsule width				
1st instar	3	0.13	0.000	0.13
2nd instar	5	0.22	0.003	0.20-0.23
3rd instar	0	0.31*		
4th instar	6**	0.40	0.006	0.37-0.47
5th instar	7**	0.61	0.006	0.57-0.70
6th instar	8	0.96	0.009	
Pupa				
Head capsule width	6	1.0	0.000	1.0
Body length	6	7.92	0.076	7.1-8.5

* Based on Dyar's law (1.4 x the previous instar)

** In part from cast head capsules

appearance and appears dwarfed and deformed compared to normal plants (Fig. 11).

The larva prepares an easy exit for the adult prior to pupation within the chamber. It first chews away material from a portion of the side of the chamber roughly 2 mm in diameter leaving a thin membrane of plant tissue at the surface. It then suspends itself in a mass of cottony webbing leaving a tunnel to the membrane at the surface. It pupates suspended in the webbing with its head toward the opening. When the adult emerges it easily breaks through the membrane to the outside. The formation of the surface membrane is an indication of the completion of the larval stage. Under field conditions the average time from formation of the chamber to pupation (formation of the membrane) is 24 days, and the average length of the pupal stage (membrane formation to breakage of membrane) is 14 days.

The adult is about 1 cm long and silver-white with black speckled wings and the rams-horn-like labial palpi characteristic of the family (Fig. 12). Upon emerging, the 1st generation females begin oviposition within 24 hours if a male is available. Mating takes place mostly at night. It was observed during the day only once in the early morning in a field cage. Moths generally remain motionless during the day perched on leaves, stems or the tops of leaf chambers. Eggs are laid on stems, leaves and flower buds. Average egg production was 100/1st generation female. The average laboratory life span of all 1st generation adults was 10.8 days. The life cycle of the insect from egg to adult emergence is about 50 days per generation (Table 3).

Second generation eggs hatch from mid to late July, by which time

Fig. 11. Horsenettle plants with heavy infestation of first generation larvae of F. nundinella.

Table 3. Life stages of *F. nundinella*.

Stage	No. Obs.	No. Days Mean	No. Days S.E.	Range
Egg[1]	42	11.5	0.18	9-14
Larva[2]	45	24.3	1.31	7-47
Pupa[2]	29	14.3	0.72	7-23
Adult[3]	11	10.8	0.54	9-15

[1] Reared in the laboratory at 24°C from 1st generation adults.

[2] 1st generation in field.

[3] 1st generation emerged in 24°C laboratory from field collected pupae.

Fig. 12. Adult of F. nundinella.

berries have begun to form on some plants. The first instars crawl about as in the first generation. If the plant has no berries on it the larvae will form leaf chambers and develop to maturity in the same manner as the first generation. In the field cages which contained colonies of F. nundinella there were very few berries and many larvae formed leaf chambers to emerge as adults in September. If there are berries on the plant, the first instar will enter a berry and develop to maturity there. In the vicinity of the caged colonies, plants which had infested berries never had leaf chambers. The same was found on an isolated plant with no berries on it as late as August 17, 1976.

Most plants bear fruit during the latter half of summer and the interior of a berry is the usual habitat for second generation larvae. The larva occupies the berry alone and feeds on developing seeds and fleshy material inside. In the early instars there is no external sign that a berry is infested. Any wound made by the first instar would be very tiny and obscured by the growth of the berry. By 4th and 5th instar, the larva has consumed a large portion of the interior of the berry and the exterior has taken on a characteristic appearance. The berry becomes misshapened and the surface dull and rough compared to normal berries which are shiny and smooth (Fig. 13). By the end of the 6th instar the berry is a hollow ball containing frass and webby material (Fig. 14). All seeds are consumed. Before pupation the larva tunnels to the surface as before and leaves a thin 2-3 mm dia. membrane covering the opening (Fig. 15). It also suspends itself in webbing with head oriented toward the opening and pupates.

Fig. 13. Normal berries (left) next to berries containing larvae of F. nundinella.

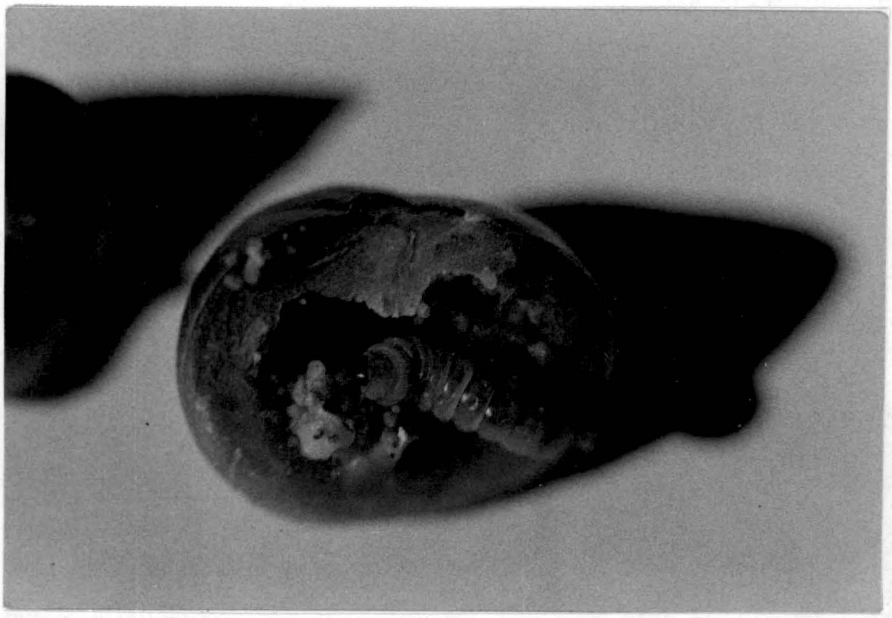

Fig. 14. Escavated berry containing 6th instar of F. nundinella.

Fig. 15. Membrane covering emergence tunnel for escape of the F. nundinella adult.

The adults of the 2nd generation emerge during September, mostly in the latter half of the month. The length of the life cycle for this generation (egg to adult) is also approximately 50 days. It is not known whether the adults mate upon emerging but no eggs are laid before winter.

In the field caged colony, no eggs could be found on leaves or stems after adults emerged in the fall whereas eggs were numerous at mid-summer after emergence of the first generation. Adults were quiescent for a period after emergence in September. By the end of September (prior to frost) no adults were in view and had presumably entered their overwintering sites.

Fig. 16 shows the increase in number of individuals over the previous season in a cage situation. This illustrates that, under more favorable conditions (protection from predators, parasites, competitors, and weather extremes) the species is capable of increasing its numbers. In an unconfined situation it is probable that eggs would be divided among more plants, reducing competition, and the impact on the horsenettle population would be greater. Fecundity would not be a limiting factor since females are capable of producing an average of 100 eggs each.

Table 4 is a list of parasites that were reared from larvae of F. nundinella. Spilochalcis dema (Chalcididae) was reared from larvae in both chambers and berries. On one occasion an individual was found inside a plastic cup in the laboratory containing eggs of F. nundinella. It had apparently emerged from a leaf chamber in the laboratory and was attracted to the eggs. It is possible that the female ordinarily oviposits on the eggs. F. nundinella is the only host recorded for

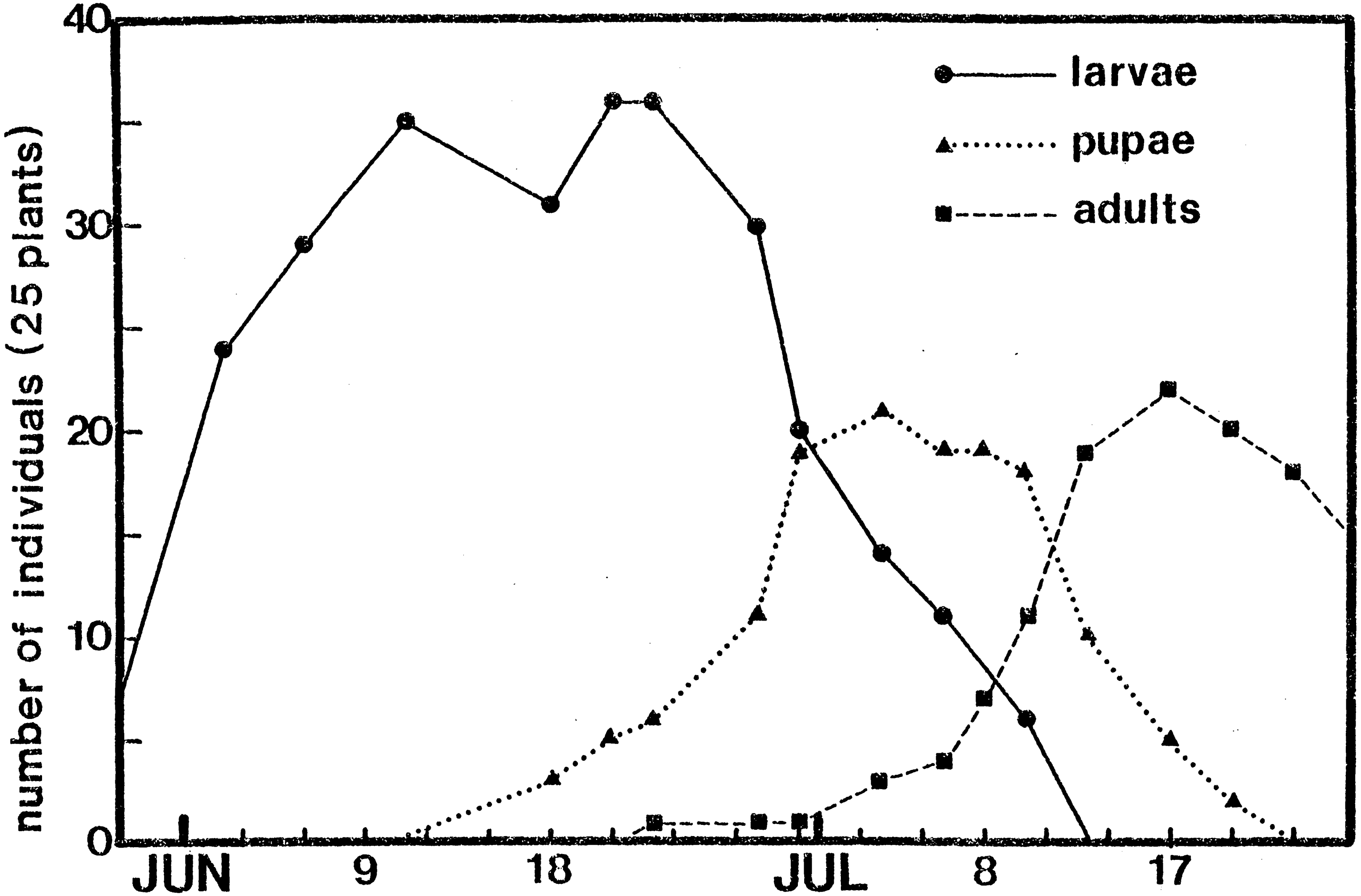

Fig.16. Relative abundance of life stages of 1st gen. F. nundinella 1977 in a field cage following the release of 21 adults in fall 1976.

Table 4. Adult parasites reared from *F. nundinella* larvae in Montgomery Co., Va.

Parasite	Emergence Date	No.	Exit from Chamber	Exit from Berry
Chalcididae				
Spilochalcis dema Burks	16-Sept-75	3		X
	19-Jul-76	1	X	
	26-Jul-77	1	X	
Eurytomidae				
Eurytoma sp. (probably *bolteri* Riley)	15-Sept-75	3		X
Braconidae				
Bracon mellitor Say	6-Sept-75	2		X
	6-Jul-76	1	X	
	19-Jul-76	1	X	
	21-Jul-76	3	X	
Ichneumonidae				
Unidentified	19-Jul-76	1	X	
	28-Jul-76	4	X	

S. dema by Peck (1963) in his Catalogue of the Nearctic Chalcidoidea or by Muesebeck et al (1951) in their Hymenoptera of America North of Mexico-Synoptic Catalog. This parasite was found in roughly 10% of the specimens collected in the field. It probably relies on highly developed host finding mechanisms because of its extreme specificity and the need to locate the well protected larvae. S. dema allows its host larva to excavate the emergence tunnel and membrane before killing it. The adult parasite may emerge from either the larva or the pupa and then exit via the emergence tunnel and membrane created for the moth.

Three females of a Eurytoma sp. were reared from larvae within berries only. It is likely to be Eurytoma bolteri because bolteri is the only Eurytoma species reported to parasitize F. nundinella (Peck, 1963). This parasite was reported by Montgomery (1933) to attack both F. nundinella and its closest relative G. gallaesolidaginis. Riley (1869) described the parasite and reported only G. gallaesolidaginis as a host. The Eurytoma species may produce up to 6 individuals per host larva. They form silken coccoons which fill the interior of the berry. The fully developed parasite larvae may overwinter inside these coccoons and pupate in the spring. As the host larva is killed before it matures, the adult parasites must chew their way to the outside. Some die inside the berry. Emerged parasites leave characteristic pinholes surrounded by a blackened area on the surface. This parasite was found in ca. 15% of infested berries in the field.

F. nundinella is one of the many hosts of Bracon mellitor Say. This opportunistic parasite finds the caterpillar an acceptable host but probably does not seek it out. Most specimens came from larvae in leaf chambers but one was reared from within a berry.

Five specimens of an unidentified Ichneumonid were reared from leaf chambers on 2 occasions; none was reared from berries. This is probably a general parasite.

Impact on Horsenettle. Larvae of *F. nundinella* have an effect on horsenettle in each generation. First generation larvae in leaf chambers do not remove a significant amount of material by feeding but their presence has a general inhibitory effect on growth and development of the host plant. Plants with at least one leaf chamber were dwarfed and deformed and formed fewer healthy flowers and berries. In an experiment measuring the impact of 1st generation larvae on growth of horsenettle, the mean dry weight of control plants compared with plants having two levels of larval infestation showed considerable difference in weight (Table 5). The number of larvae which infested the plant was not as important. Apparently, the inhibiting effect of the larvae was not cummulative.

By the second generation, the plants have attained most of their growth. Larvae which produce chambers do not appear to have an effect on growth or reproduction but those which develop in berries could have a significant impact on seed production. Since each larva consumes the entire seed content of its berry, a high larval population could cause complete seed destruction in an area. This would eliminate dispersal of the weed by seed, probably the major source of new infestations of horsenettle.

Table 5. Impact of 1st generation larvae of F. nundinella on dry weight of horsenettle.

Variable	No. Obs.	Dry Weight of Horsenettle (g)		
		Mean*	S.E.	Range
Control	21	1.69a	0.37	0.3-7.5
1-2 Larvae/Plant	11	0.37b	0.11	0.1-0.8
3-6 Larvae/Plant	8	0.41b	0.13	0.2-1.3

* Means followed by the same letter do not differ significantly ($P < 0.05$) as determined by Duncan's multiple range test.

Host Specificity. There is no literature or specimen record of any host other than horsenettle for F. nundinella. I have not observed infestation of any other plant species either in nature or in the laboratory. When male/female pairs of the first generation were released into three cages containing different combinations of solanaceous plants, none became established. Careful examination one month after release revealed no signs of eggs, larvae, pupae or characteristic damage on any of the plants. It may be that the moths failed to mate and lay eggs before dying or that they did not find suitable sites for oviposition among the plants that were available.

In July of 1977 potted plants of pepper, eggplant, and tomato were placed in a field cage containing a colony of F. nundinella adults which were actively ovipositing on horsenettle plants in the cage. The pots were replaced each week and checked for eggs. All non-horsenettle plants were free of eggs except one pepper plant which had seven eggs on the underside of one leaf. This isolated case was probably due to the heavy oviposition pressure in the cage at that time. Most horsenettle leaves in the cage had a large number of eggs and it is possible that females seek leaves with few or no eggs present to reduce competition among larvae. Although a few eggs were on pepper plants, it is unlikely that the special needs of developing larvae could be met. The pepper plant may be nutritionally suitable, but would probably not respond to the habitat requirements of the larvae and pupae. Only 1 of the 7 eggs on the pepper leaf hatched, and the first instar crawled about 5 cm and died within a 2 day period. Eggs and first instars produced by adults in the laboratory which were placed on buds and leaves of a potted pepper plant (total of 50 eggs and 17 larvae), did not develop on the plant nor were there any signs of damage to the plant. Horsenettle is apparently the only suitable host for F. nundinella.

Results of this study show that F. nundinella has many of the basic qualifications of a good biocontrol agent:

(1) It is apparently host specific.

(2) It has a significant impact on growth and development of the plant in early summer, even a single larva can inhibit plant growth.

(3) It attacks the fruiting structures of the plant and has the potential to eliminate seed production.

(4) Two generations attack the plant, each in a different manner, creating a possible cumulative effect.

(5) Females have the potential for relatively rapid population buildup under favorable conditions.

(6) Although two of its major hymenopterous parasites are quite host specific, their absence in other parts of the world where horsenettle is a problem might allow F. nundinella populations to reach high levels when released in these areas.

F. nundinella is not effective in controlling horsenettle in Western Virginia in spite of its numerous desirable qualities. This is probably due to the low population density of the insect. Both plant and insect are native to the region and have probably been co-evolving for thousands of years. In such a situation, a parasite is not likely to overwhelm its host but will instead maintain a steady state defined by the constraints which have evolved with it. The same is true for the host. Factors which are probably important in keeping populations of F. nundinella within its limits are:

(1) Specific and general parasites.

(2) Interspecific competition (especially flea beetles).

(3) Intraspecific competition for feeding sites (probably only important in a high density situation).

(4) Weather conditions which promote diseases or dessication of larvae.

(5) Predation of exposed first instars.

If any of these factors were eliminated or reduced it is possible that a shift in the balance would occur which would allow for a much higher population density. Such an increase might reduce the general vigor of the horsenettle population sufficiently to make it loose its competitive edge in the ecosystem. This would enhance the effects of climate, competition and the impact of other herbivor species on the weakened horsenettle population, decreasing its importance in the plant community.

It is not likely that such a scenario could take place within the insect's native range, for it would be impractical, or prohibitively expensive, to remove limiting factors. If, however, insects were released into areas where horsenettle is an introduced problem it is quite possible that a lack of parasites, reduced competition, or improved climatic conditions would allow a significant insect population buildup and a resulting decline in density of horsenettle.

Other Insects Associated with Horsenettle

The insects represented in this survey are, for the most part, general feeders or well-known pests of economically important plants closely related to horsenettle. The major species are summarized in Table 6.

From the order Diptera there were three species. Maggots of the Tephritid fly Zonosemata electa were commonly found infesting the mature fruits in late August. In September the fully developed maggots dropped to the ground, pupated in the soil, and spent the winter in the puparia. Exposure to higher temperatures in the laboratory at mid-winter broke diapause and allowed the adults to emerge. According to Burdette (1935) the insect has but one generation per year in New Jersey with adults being active from June 20 to August 12. The situation in Virginia is probably similar because adult activity would coincide well with the formation of berries on horsenettle plants. Z. electa is well-known as a pest of peppers and eggplants (Burdette, 1935).

Adults of another Tephritid fly, Eurosta bella, were collected from the leaves of horsenettle on several occasions but no biological information was obtained. The third representative was an unidentified dipterous gall collected from a horsenettle stem on one occasion.

Besides F. nundinella, the other lepidopterous larva found feeding on the weed was the tobacco hornworm Manduca sexta. The latter was found on several occasions devouring leaves and stems of horsenettle. One individual was capable of consuming an entire 1 m high plant. M. sexta is a common pest of tobacco and tomato.

In the Homoptera, species of Cercopidae, Cicadellidae and Flatidae were commonly encountered but none appeared to be damaging the plants. The Hemipteran, Lygus lineolaris, a general feeder, was encountered throughout the growing season feeding on the leaves but was apparently not affecting the plant.

Members of the Coleoptera were the most numerous. The most common species at any time were the flea beetles, (Epitrix fuscula and other

Epitrix species). Leaves were frequently riddled with holes from adult feeding; some plants were almost totally destroyed. Horsenettle is probably an important alternate host for flea beetles which feed on crop plants.

Adults of the potato stalk borer, *Trichobaris trinotata* were frequently seen on the tops of young horsenettle shoots in early spring. The larvae were observed to bore downward through the centers of the stems and pupate at ground level. The adults emerged and remained in the stem for the winter. The plants appeared to be unaffected by the feeding in the pithy center.

Adults of an *Apion* species (Apionidae) were often seen on flowers or buds throughout the summer. Larvae of a very small curculionoid, which may be the same species, were found feeding inside the male structures of the flowers of horsenettle on one occasion.

A tortoise beetle, *Coplocycia clavata*, was found feeding on a horsenettle leaf on one occasion. Specimens of this beetle have been collected from potato. Japanese beetles, *Popillia japonica*, were often found in large numbers feeding on foliage of horsenettle.

The Chrysomelid beetle *Leptinotarsa juncta* (Germar) was commonly observed feeding on foliage of horsenettle and bittersweet nightshade (*Solanum dulcamara*). This insect is a close relative of the Colorado potato beetle and has a similarly voracious appetite. Adults lay eggs on undersides of leaves throughout the growing season. Larvae feed in groups on the leaves and may sever stems or petioles. After pupation in the soil, adults return to the tops of the plants and feed along the edges of the leaves. They have 2-3 generations per year in Southwest Virginia.

On one occasion 3 mature larvae were found feeding on leaves of eggplant in a backyard garden. These were brought to the laboratory and they subsequently pupated to emerge later as adults. When wild adult females were tested for ovipositional preference, no preference was shown for either horsenettle or eggplant. During the six day period of the test 66 eggs were laid on horsenettle leaves and 61 were laid on eggplant. Adults fed on both plants.

When larvae were released into cages containing horsenettle plants, mortality was high. Plants grew vigorously in each cage and there was no apparent difference in impact from the different numbers of larvae.

About 35% of larvae collected from the field were parasitized by one of two tachinid flies; Doryphorophaga doryphorae (Riley) and Adoryphorophaga abberans (Tns.). Both are common parasites of the Colorado potato beetle (Kelleher, 1966 and Briand, 1958).

Table 6. Insects associated with horsenettle in southwest Virginia.

Order	Species	Family	Plant Part Affected	Apparent Damage	Abundance*	Notes
Diptera:						
	Zonosemata electa	Tephritidae	fruit	larva consumes and initiates decay of seeds	moderate	pest of pepper and eggplant; 1-2 maggots/fruit
	Eurosta bella	Tephritidae	- - -	- - -	low	taken from leaves
	Dipterous gall-maker	- - -	stem	abnormal swelling of stem tissue; plant otherwise normal	low	
Lepidoptera:						
	Frumenta nundinella	Gelechiidae	fruits and growth tips	larva consumes seeds; general stunting of growth	low	host specific
	Manduca sexta	Sphingidae	leaves, buds, stems	larva consumes large amount of plant material	low	pest of tobacco and tomato

Table 6 (continued). Insects associated with horsenettle in southwest Virginia.

Order Species	Family	Plant Part Affected	Apparent Damage	Abundance*	Notes
Hemiptera:					
Lygus lineolaris	Lygaeidae	leaves	none	moderate	common general feeder
Coleoptera:					
Epitrix fuscula and other *Epitrix* spp.	Chrysomelidae	leaves	adults cause "shot hole" damage to leaves when numerous	very high	pests of eggplant, tomato, potato, tobacco
Trichobaris trinotata	Curculionidae	stem	larva bores through pithy center; no apparent effect on the plant	moderate	also bores in stalks of potato
Apion sp.	Apionidae	flowers	larvae (probably) feed inside male structures of flowers	moderate	adults often seen on flowers and buds

Table 6 (continued). Insects associated with horsenettle in southwest Virginia.

Order	Species	Family	Plant Part Affected	Apparent Damage	Abundance	Notes
Coleoptera: (continued)						
	Coplocycia clavata	Chrysomelidae	leaves	larvae and adults feed on surfaces of leaves	low	reported from potato
	Popillia japonica	Scarabaeidae	leaves	adult feeding	high	common general feeder
	Leptinotarsa juncta	Chrysomelidae	leaves, buds	larval and adult defoliation	moderate	larvae will develop on eggplant
Homoptera:						
	Many unidentified species	Cercopidae Cicadellidae Flatidae	leaves	none	high	common general feeders

* low = encountered rarely or after thorough search

moderate = commonly encountered in the field

high = nearly always present

very high = always abundant

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BIOLOGY AND ECOLOGY OF

FRUMENTA NUNDINELLA (ZELLER) (LEPIDOPTERA: GELECHIIDAE)

AND ITS IMPACT ON HORSENETTLE (SOLANUM CAROLINENSE L.)

by

Thomas Earl Bailey

(ABSTRACT)

Horsenettle is a persistent, native, perennial weed of pastures and cornfields in southwest Virginia. A survey of insects associated with the weed revealed a number of general feeders, several insect pests of economic plants related to horsenettle, and a few lesser known species.

The moth, Frumenta nundinella, demonstrated a high degree of host specificity in the tests conducted. The larvae attack the plant in two ways: first instars web the terminal leaves together and form a round hollow chamber within which they feed on the growth tip of the plant, or they enter berries and consume all of the seeds. There are two generations per year, each being about 50 days. The insects overwinter as adults. Females oviposit in the spring and mid-summer. Normally first generation larvae occupy leaf chambers and second generation larvae occupy berries. In the absence of berries, leaf chambers will be formed. Predation, dessication and interspecific competition with first instars appear to be important mortality factors. Four Hymenopterous parasites were reared from the larval or pupal stages.

First generation larvae in leaf chambers significantly reduce ($P < .05$) dry weight of horsenettle regardless of the number of larvae on the plant. The second generation reduces seed production.

F. nundinella was found to be present in 9 counties in western and northern Virginia but population levels were low in all the survey areas.