Seasonal Life History of the Beet Leafhopper, *Neoaliturus tenellus* (Hemiptera: Cicadellidae), on Cool and Warm Season Weeds in Southern New Mexico[1]

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Abstract The life history of the beet leafhopper, *Neoaliturus* (*Circulifer*) *tenellus* (Baker) (Hemiptera: Cicadellidae), was studied on weed hosts in southern New Mexico from January 2008 through December 2009. Weekly counts of leafhopper adults, nymphs, and eggs were taken from London rocket, *Sisymbrium irio* L., and kochia, *Bassia scoparia* (L.) A. J. Scott, at two field sites, and the relationship between leafhopper and phenology of the host plant was documented. The presence and abundance of the eggs, nymphs, and adults during the year suggest this species is univoltine in agricultural regions of southern New Mexico, with some evidence of a second generation. Changes in the timing of kochia emergence and the beet leafhopper flights were noted in 2016–2017 and again 2020–2023. Previous studies on voltinism are reviewed for this species, and the implications for management of the beet leafhopper are discussed.

Key Words *Neoaliturus tenellus*, *Circulifer tenellus*, beet leafhopper, life history, curly-top virus

The beet leafhopper, *Neoaliturus* (=*Circulifer*) *tenellus* (Baker), is a vector of multiple plant pathogens, including curtoviruses. Curtoviruses are a source of significant economic damage to a wide range of vegetable crops across the western United States acquired by *N. tenellus* from common weed reservoirs. The life history of the leafhopper is well documented in the general sense, due to its economic significance as a pest. It is known to prefer two general habitats depending upon the time of year: (a) rangeland/native desert and (b) in and around agricultural fields (Ball 1917, Carter 1930). It passes the winter as an adult, which is common for members of the family Cicadellidae (Delong 1971).

There are many competing reports on the number of annual generations of *N. tenellus*. As Delong (1971) has pointed out, the number of generations per year of a given cicadellid species is dependent upon the geographic area, host plant species, and even the state of the host plant on which the generation occurs. So, variations in timing of development and, potentially, numbers of generations are expected depending upon location and climatic conditions; however, this is

potentially confounded by variable reports in the literature. This confusion comes in part as a result of unreliable comparisons between field studies and those undertaken in caged conditions and due to an absence of agreement by authors in what constitutes a generation. A summary of the available literature regarding voltinism of *N. tenellus* is shown in Table 1.

Current and relevant information on the life history of *N. tenellus* in New Mexico is limited. Romney (1939) reported two spring broods in southern New Mexico each year, hinting at (though not supporting) additional generations later in the year. A definite relationship exists between the abundance and condition of newly germinated plants in the fall and economic damage to crops by the leafhoppers in the spring, demonstrated by Romney (1939), suggesting the importance of vegetation-sustaining rainfall in the movements of adults between irrigated regions and the arid Chihuahuan desert of southern New Mexico. This is a pattern unlikely to have changed significantly since Romney reported it in 1939, and in fact was confirmed with anecdotal evidence by Ray et al. (2005). In the Chihuahuan desert of southern New Mexico, *N. tenellus* has been reported from a variety of desert plant species, predominantly in the fall (Logarzo et al. 2002). Also in southern New Mexico, Creamer et al. (2003), using yellow sticky trap collections in agricultural areas, reported that adult populations of *N. tenellus* increased in mid-April, remained high throughout the summer, and decreased in late October to mid-November. The numbers of leafhoppers that move through a field and the exact timing has varied slightly from 2001 to 2023, although the patterns of movement have remained similar (Creamer et al. 2023, Lehnhoff and Creamer 2020).

Romney (1939) concluded that mesa pepperwort, *Lepidium alyssoides* Gray, was the source of roughly 90% of the spring generation of *N. tenellus* in southern New Mexico, which invaded further North and Northeast into surrounding states throughout the growing season each year, and to nearby irrigated regions as the plant senesced. This host plant now is reported as scarce, at least in the Mesilla Valley of southern New Mexico (Creamer et al. 2003, Ray et al. 2006). A change in beet leafhopper host plant succession likely has occurred since Romney's study. The winter annual London rocket, *Sisymbrium irio* L., and the summer annual kochia, *Bassia scoparia* (L.) Schrader, are good candidates for this succession due to reports of adult leafhoppers on these plants (Cook 1967, Ray et al. 2005), their status as curtovirus reservoirs in the area (Creamer et al. 2003), and their current widespread occurrence in disturbed habitats throughout southern New Mexico. New Mexico populations of the leafhopper have shown distinct feeding preferences for Kochia over most crops and weeds (Hudson et al. 2010) and both were found infected with curly top in southern New Mexico (Lam et al. 2009).

Presented here is the seasonal life history of the beet leafhopper in southern New Mexico.

Materials and Methods

Life history. The field study was conducted in the Mesilla Valley of southern New Mexico at the Leyendecker Plant Science Research Center south of Las Cruces, NM. The surrounding habitat is Chihuahuan desert. Weekly counts of leafhopper adults and nymphs (sampling initiated second week of January 2008) and eggs (sampling initiated second week in March 2008) were taken from London

Table 1. Review of the literature* on voltinism for *N. tenellus*.

Number of Generations	Sampling Location(s)	Data Collection Method	Life Stages Sampled†	Primary Host Plants Sampled	Reference
1	UT, ID, OR, CA, AZ	Collections from field-caged adults and dissections of adult females	E, N‡, A	*Beta vulgaris*	Ball 1907
2, occasionally 3–4	CA	Unspecified field observations and cage studies.	E§, N‡, A	*Beta vulgaris*, Others	Stahl 1920
1	ID				
2, partial 3rd	ID	Sweep net collections	N‡, A	*Beta vulgaris, Descurainia pinnata, Salsola tragus, Sisymbrium altissimum*, Others	Haegle 1927
2–3	CA	Cage studies and unspecified field observations.	E‖, N‡, A	*Beta vulgaris, Erodium cicutarium, Sisymbrium altissimum*, Others	Severin 1930
3 (2 on beets)	ID	Sweep net collections	unreported	*Beta vulgaris*, Others	Carter 1930
3	UT	Sweep net collections and square-yard counts	N‡, A	*Beta vulgaris*, Others	Knowlton 1932
3+	WA, OR	Sweep net collections, square-yard counts, and dissections of adult females	E, N‡, A	*Erodium cicutarium, Sisymbrium altissimum, Salsola tragus*, Others	Hills 1937

Table 1. Continued.

Number of Generations	Sampling Location(s)	Data Collection Method	Life Stages Sampled†	Primary Host Plants Sampled	Reference
2+	NM, CO, TX	Sweep net and cylinder collections	N¶, A	*Beta vulgaris, Lepidium alyssoides*	Romney 1939
2–3	ID	Field "sampling cage" collections	E#, N, A	*Beta vulgaris*, Others	Harries and Douglass 1948
3+	WA, OR	Sweep net and sticky trap collections	N‡, A	Mixed weeds near commercial potato fields	Munyaneza et al. 2007
2	WA, OR	Sticky trap collections	A	Margins of commercial potato fields	Murphy et al. 2012

* Only original studies, review publications not included.
† Life stages: E = Egg, N = Nymph, and A = Adult. Nymphal instars were determined unless otherwise noted.
‡ Nymphal instars not determined.
§ Method of egg sampling not reported.
‖ Eggs collected from caged populations.
¶ Nymphal instars not determined other than single reference to first instars.
# Eggs collected from field collections of plant tissue.

rocket and kochia from two adjacent, semi-permanent field sites, Leyendecker (32° 12′ 12.14″ N, 106° 44′ 29.47″ W) and Weed Farm (32° 12′ 11.07″ N, 106° 44′ 36.03″ W), throughout 2008 and 2009. The Leyendecker site consisted of weeds, periodically managed by the grower, on the edge of an alfalfa field; the Weed Farm site consisted of a small plot (0.03 ha) at the NMSU Weed Science Field Research Facility, maintained specifically for weed growth. Each week, life stages of the host plants were documented based on the dominant life stage of the sampled weed patch in the field and from pictures taken at the time of collection. The host weed life stage categories recorded were vegetative, blooming, blooming + seed, in full seed production, and desiccated.

For each collection date, two different sampling methods were performed to ensure collection of both adults and nymphs: funnel bucket and sweep net. The funnel bucket (modified from Knutson 2010) consisted of a 18.9-L water container with the bottom removed, inverted, and connected (via the neck) to a plastic Nalgene© (300 ml) container. A plant was shaken vigorously 15 times over the large opening of the bucket; a sample consisted of shakes from 10 plants at each site. The sweep net (38-cm diameter) sample consisted of two sets of 25 sweeps per site. Samples of nymphs and adults collected in the field were taken to the laboratory and frozen, then sorted and preserved in 85% EtOH; numbers of each instar and sexes of adults were recorded for each sample taken.

Leaf samples of each plant species (20 and 40 entire leaves, London rocket and kochia, respectively) were taken from field sites weekly to check for the eggs of *N. tenellus*. More leaf samples were taken from kochia than London rocket to compensate for relative differences in leaf size between species. The veins on both sides of sampled leaves were scanned with a dissecting scope and numbers of eggs recorded. Recovered eggs were placed in a Petri dish (≈ 10 cm in diameter, 2 cm in depth) containing moistened filter paper in a growth chamber maintained at 25°C until first instars emerged to verify the species. Illustrations by Cook (1941) and preserved specimens of the egg and five nymphal instars from a laboratory colony of *N. tenellus* were used to verify species and developmental stages of field samples.

Trapping of beet leafhoppers was also done at Leyendecker Plant Science Research Center using yellow sticky traps placed around the margins of chile fields 2016–2023 changed every 1–2 wk. Four yellow sticky traps (20 × 25 cm) (Hummert International, Earth City, MO) were placed approximately 60 cm from the ground at the margins of the fields. Sweeps, approximately 10/collection spot, were done at from nearby living weeds at the same time that traps were changed.

Voucher specimens. Selected samples of all life stages of *N. tenellus* have been vouchered in the New Mexico State Arthropod Museum in Las Cruces, NM.

Results and Discussion

Life history. Seasonal abundances of *N. tenellus* and the two weed hosts are presented here by year to more accurately represent the distinctions in generations (Note: beginning and ending dates of collections of first instars are difficult to distinguish because of small sample size) and yearly phenologies of the plants.

Adult beet leafhoppers were found throughout the year on the weed hosts in the first year of the study (Figs. 1, 2). Eggs were collected discontinuously from the second week in March (when egg sampling was initiated) through the third
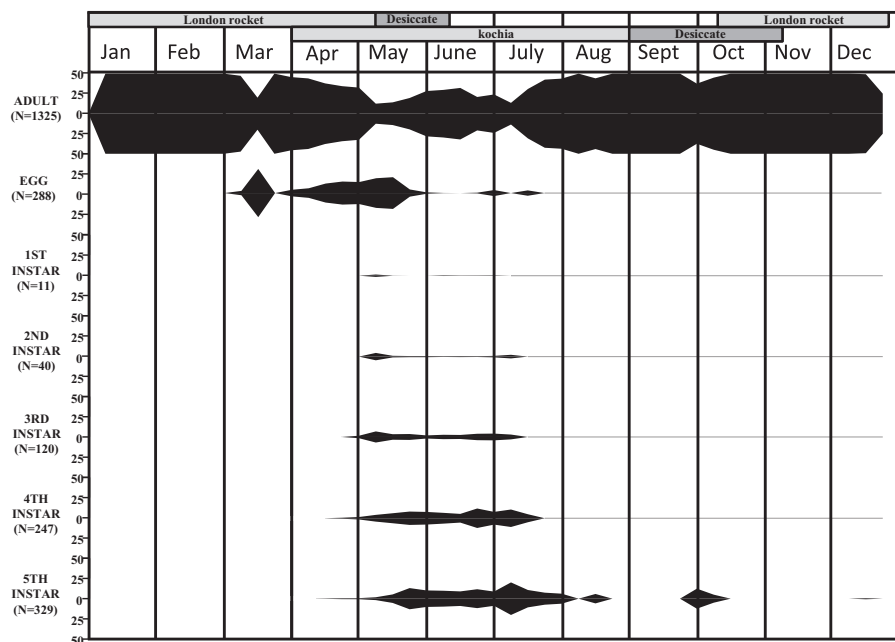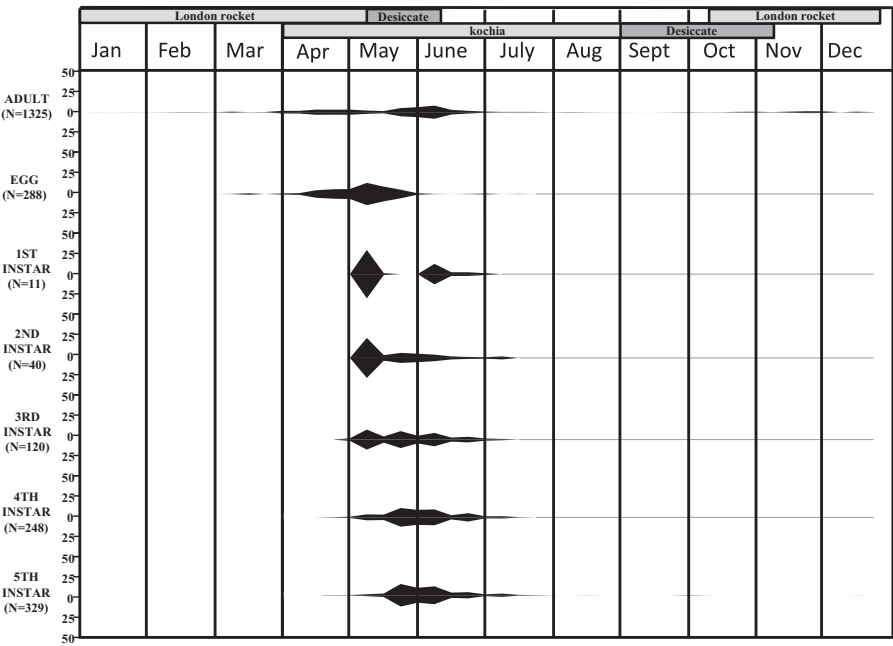
Fig. 1. Life cycle of *N. tenellus* in the field. Percentage of individuals of each stage per sample collected during 2008. Beginning and end points of each shaded area represents sample dates preceding and following collections of specimens, respectively.

week of July; eggs were deposited on the undersides of leaves in plant tissue on or adjacent to leaf veins. First instars were collected discontinuously from the second week in May through the fourth week of June, second instars from the second week of May through the second week of July, third instars from the third week of April through the second week of July, fourth instars from the third week of April through the third week of July, and fifth instars from the third week of April through the fourth week in July and again the first week in October and the second and third weeks of December.

London rocket was in bloom when sampling was initiated in January and was producing seed from the second week in March through the second week in May. The transition from London rocket to kochia in the spring was complete by the fourth week in May, when kochia had emerged and London rocket was desiccated. Kochia was in bloom during the entire month of August and was producing seed from the third week in August through the second week in October. London rocket emerged and was in its vegetative stage by the third week in October through the first week of November. The transition from kochia back to London rocket in the fall was complete by the first week of November, when kochia was desiccated and London rocket was vegetative.

Adults were found from the first week of January through the third week of December in 2009 (Figs. 3, 4). Eggs were found from the third week of January through the first week of May and from the first week in August through the second
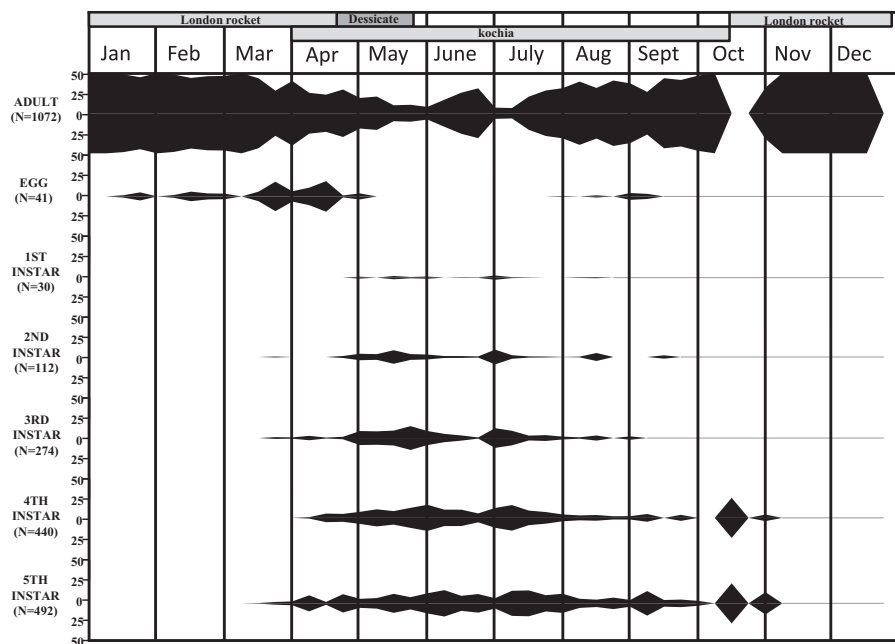
Fig. 2. Life cycle of *N. tenellus* in the field. Percentage in each sample of total individuals of same stage collected during 2008. Beginning and end points of each shaded area represents sample dates preceding and following collections of specimens, respectively.

week of September. First instars were found discontinuously from the fourth week of April through the third week of August, second instars (discontinuously) from the fourth week of March through the second week of September, third instars from the fourth week of March through the first week of September, fourth instars (discontinuously) from the second week of April through the first week of November, and fifth instars (discontinuously) from the first week of April through the first week of November.

London rocket was in bloom when sampling was initiated at the first week of January and was producing seed from the third week in January through the second week in May. The transition from London rocket to kochia in the spring was complete by the third week in May, when kochia had emerged and London rocket was desiccated. Kochia was in bloom by the third week in August and producing seed from the fourth week of August to the second week in October when plants were destroyed by the grower. London rocket had emerged and was in its vegetative stage by the third week in October. The transition from kochia back to London rocket in the fall was completed by the third week in October, when kochia had been removed and London rocket was vegetative.

Timing of London rocket and Kochia emergence and desiccation varied year to year (2016–2023) and changed somewhat over time. Years with higher rainfall in October and November led to abundant London rocket emergence during that
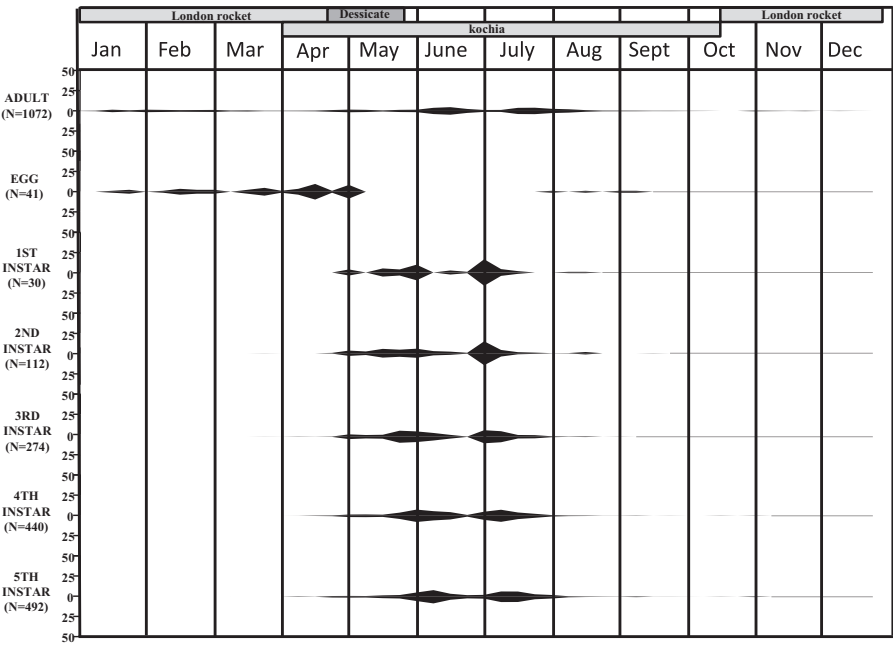
Fig. 3. Life cycle of *N. tenellus* in the field. Percentage of individuals of each stage per sample collected during 2009. Beginning and end points of each shaded area represents sample dates preceding and following collections of specimens, respectively. Note: Kochia was destroyed after the second week in October.

time (2018, 2019, 2022). Desiccation of London rocket during the time varied from early April to mid-May. Kochia was observed to emerge continuously March through June 2016 (Fig. 5). In contrast, in 2017, Kochia emergence was documented from 31 January through mid-May and then in two later episodes in mid-June and mid-August (Fig. 6). Desiccation of Kochia was noted mid to late October most years.

Host sequence. Comparisons of the life cycle of *N. tenellus* on the two weed hosts showed a sequential colonization from the winter annual, *S. irio*, to the summer annual, *B. scoparia*, and back to *S. irio* during the course of each year. Specifically, on *S. irio*, adults were present from shortly after plant emergence until plants were completely desiccated (October through the end of May or early June). Eggs were present discontinuously from when plants were in bloom (third week in January) through plant senescence (third week in May). Nymphs were found to be present on London rocket in the vegetative stage in small numbers, only in the third week in October and in the first week in November. They were not present on blooming London rocket and were found on London rocket in the blooms + seed stage in small numbers from the third week in March through the end of April. Field collection of nymphs was greatest from London rocket that had completely gone to seed (first week in April through the second week in May,

Fig. 4. Life cycle of *N. tenellus* in the field. Percentage in each sample of total individuals of same stage collected during 2009. Beginning and end points of each shaded area represents sample dates preceding and following collections of specimens, respectively. Note: Kochia was destroyed after the second week in October.

peaking the first week in May) and were found on fully desiccated plants through the first week of June. On *B. scoparia*, adults were present from plant emergence through plant senescence (early April through mid-November). Eggs were present discontinuously from when plants were vegetative through seed production/beginning of plant desiccation the first week in April through the second week in September. Nymphs were present on kochia almost exclusively during its vegetative stage from the beginning of April, when the plant emerged and was large enough to sample, through the second week in August. Nymphs were present on kochia through plant desiccation in the second week of October. Populations of *N. tenellus* on both hosts overlapped from April through June. Even though eggs were deposited as early as January in London rocket, the timing and sequence of nymphal development was similar for both plant species during the spring, that is, nymphs were found at the same life stages on both plants as London rocket was senescing and kochia was in vegetative growth.

The relative numbers of nymphs and adults of *N. tenellus* on both host plants indicate that kochia is the source of much higher populations of the leafhopper than London rocket. During this study, approximately twice as many adults were collected from kochia (n = 2,105) than from London rocket (n = 1,081). The majority (≈94%) of nymphs were collected from kochia and, of these nymphs, nearly all
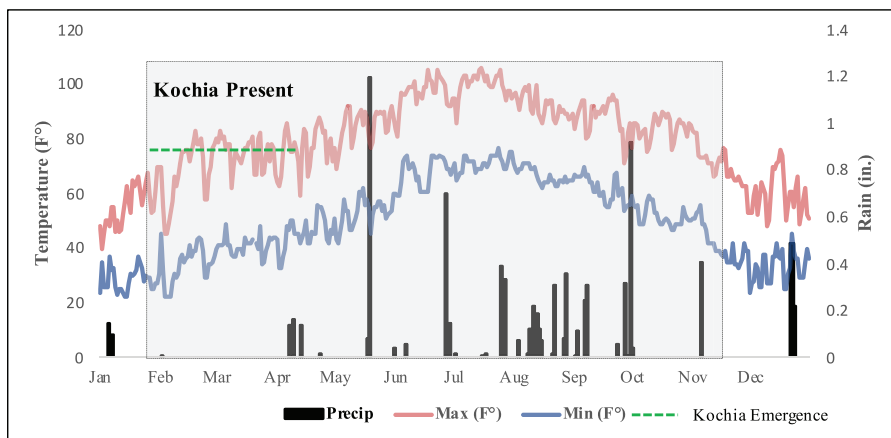
Fig. 5. Kochia emergence and presence with daily temperature and precipitation in 2016 at Leyendecker Plant Research Science Center. Data retrieved from weather station on site. Dates of Kochia emergence are denoted with a green dashed line and Kochia presence is indicated by the shaded box.

(≈99%) were produced during the vegetative stage of this host (beginning of April through the second week in August).

Conversely, much higher numbers of eggs were collected from London rocket (n = 246, 2008; n = 34, 2009) than from kochia (n = 42, 2008; n = 4, 2009). Given the
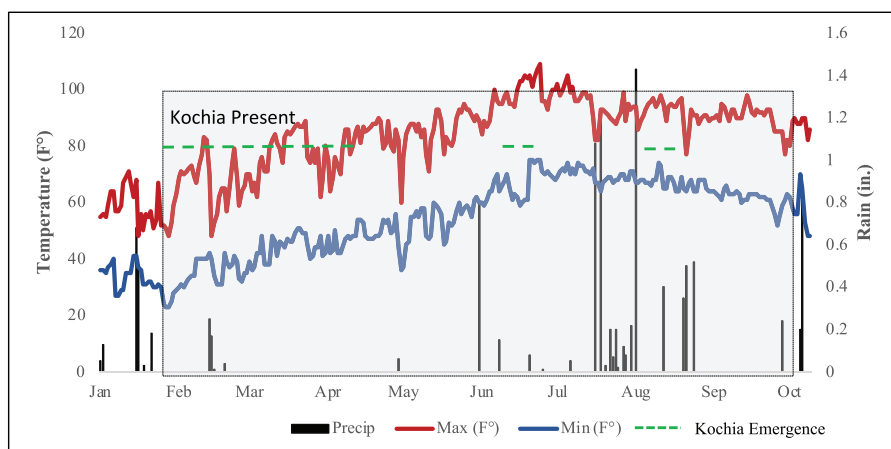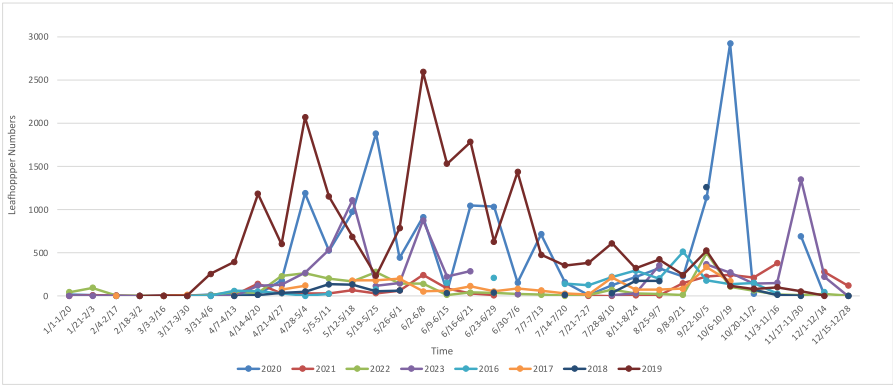

Fig. 6. Kochia emergence and presence with daily temperature and precipitation in 2017 at Leyendecker Plant Research Science Center. Data retrieved from weather station on site. Dates of Kochia emergence are denoted with green dashed lines and Kochia presence is indicated by the shaded box.

Fig. 7. Beet leafhopper numbers collected from yellow sticky traps at Leyendecker Plant Research Science Center 2016–2023. Traps changed every 1–2 weeks. Numbers are totals from four traps placed at margins of cultivated field blocks.

timing and subsequent nymphal populations on the plants, this could indicate that (a) London rocket could not support development of the majority of the nymphs from these eggs due to senescence or (b) a sampling bias error that favored London rocket.

Yellow sticky trap collection data are presented for 2016–2023 (Fig. 7). The numbers of leafhoppers trapped at the initial peak of flights in April and May generally correlated with the prior October and November rainfall as predicted from a model developed from 2001–2018 data (Lehnhoff and Creamer 2020). The date of the initial flight corresponds to the dry down of London rocket and other winter annual weeds. A large fall peak corresponded to dry down of Kochia and other summer annual weeds. Sweeps data are presented for the same years (Table 2). Generally, leafhoppers were found in sweeps during the same time that they were found from yellow sticky traps, that is, beginning in mid-April – mid-May and continuing until mid-October. Notable exceptions were leafhoppers collected from yellow sticky traps and sweeps in December 2021 and January 2022.

Table 2. Leafhoppers collected using sweep nets.

Year	First Date Collected	Date of Largest Number Collected	Last Date Collected
2019	5/31	5/31	10/11
2020	5/1	5/21	10/16
2021	6/4	9/16	10/15 (12/21*)
2022	5/5	5/26	9/30
2023	4/21	9/22	11/17

* No leafhoppers were collected between the two dates.

Voltinism. The beet leafhopper appears to have one distinct generation on weed hosts in agricultural regions of southern New Mexico with some evidence that it could be bivoltine. Specifically, one generation appears to have been completed on weed hosts each year during 2008–2009, with a small cohort of late-season nymphs occurring in early October and mid-December in 2008 (Figs. 1, 2) and an apparent extension of nymphs present through early November in 2009 (Figs. 3, 4). The findings in both years support claims made by Ball (1917) of one large annual generation in the southwestern United States. The evidence for a single generation is not considered abnormal in comparison with other members of the Cicadellidae, most of which are univoltine (Triplehorn and Johnson 2005). However, the late season presence of fifth instars in the second and third week of December in 2008 (Fig. 1), and the extension of oviposition through the second week in September (Figs. 3, 4) in 2009, indicate the potential for a partial second generation, possibly occurring predominantly on desert hosts in late summer and fall when adult numbers are reduced on weeds in agricultural areas. Romney (1939) reported two generations for New Mexico in spring and early summer and suggested additional generations with the following oddly-worded statement: "Breeding…continues throughout the normal breeding season of the mustard [*Lepidium alyssoides*]." However, he only reported nymphs from May, June, and August. Further, nymphs of his two spring "broods" (May and June) were separated based on size (no additional information given). Though he mentions first instars once, no additional separation of instars is given. Our data show a single generation occurring during this time.

Given the emergence of Kochia continuously in mid to late spring in 2008 and 2016, a corresponding continuous single generation of beet leafhoppers would likely be present, leading to a single observable brood. The early emergence of Kochia in 2017 followed by two additional emergence events later in the season could lead to distinct generations of leafhoppers. The presence of leafhoppers in London rocket in December 2021 through January 2022 followed by a hard freeze also could lead to a temporally separated early generation.

Management. The logical approach to management of the beet leafhopper/ curtovirus complex would appear to be targeting key weed hosts, which serve as reservoirs of both virus (Creamer et al. 2003) and leafhoppers. Elimination of London rocket in the fall, shortly after plant emergence, should greatly impact populations of overwintering beet leafhoppers in/near cultivated areas and thus reduce oviposition early the following year. According to Hills (1937) in Washington, the possibility of the fall as a period of mortality for overwintering beet leafhoppers due to absence of newly germinated host plants is great in comparison to overwintering mortality. In the Columbia Basin of Washington and Oregon, Murphy et al. (2012) found fall and overwintering conditions to be the most prominent influence on beet leafhopper populations. Also, there is evidence that high curtovirus incidence in crops consistently is related to fall (October and November) rainfall in southern New Mexico (Romney 1939), and rainfall during this period is correlated with London rocket emergence (Ray et al. 2006) and higher beet leafhopper numbers at initial flights in April-May (Lehnhoff and Creamer 2020). Therefore, removal of London rocket as it emerges in the fall also should reduce the impact of curtoviruses on crops the following spring. Management of kochia should be targeted for control

as it emerges because the majority of development of populations of *N. tenellus* (95% of adults and 99% of nymphs) occurs during the vegetative stage of the plant. Kochia and London rocket, as annual plants, are most susceptible to control measures in the seedling to early vegetative stages of growth. For long term management, control of these plants prior to flowering and seed set is essential. Since Kochia can also emerge later in the season, those plants would need to be removed also.

Weed management could be considered on an individual basis or as an area wide strategy. With either of these strategies, it is important to recognize that the mobility of adult *N. tenellus* extends beyond cultivated regions and into rangeland, so that rangeland management could have as large an impact on beet leafhopper populations as weed management in cultivated regions. In addition, considering the wide distribution of both these weed species throughout the region, additional research is warranted to determine where to target weed control efforts to be most effective in reducing curtovirus incidence.

Acknowledgments

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