Pestiferous Rangeland Grasshopper Forage Use in the Northern Plains

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How much forage do grasshoppers use? The quantity of rangeland forage used (consumed and destroyed) by pestiferous rangeland grasshoppers during a growing season varies with stage of life cycle development, metabolic weight (dry weight) of each life stage, density (grasshoppers per square yard) of each life stage, period of hatch, and days of longevity from hatch to death.

Grasshopper Life Cycle

Grasshoppers in the Northern Plains have a one year life cycle with an active period that occurs, during most years, from early May to mid October. Grasshoppers transition by simple metamorphosis through three life stages; egg, nymph, and adult. The majority of grasshoppers' life cycle is egg-nymph-adult-egg. A few grasshopper species spend the winter period as an hibernating mid to late stage nymph. Their life cycle is nymph-adult-egg-nymph.

Grasshopper egg hatch ususally occurs from early May to late July. Eggs of grasshopper species tend to hatch during the same periods each year. The seasonal hatch periods of grasshopper species have been categorized into five hatching groups. The very early (VE) hatch occurs from late April to early May; the early (E) hatch occurs from mid to late May; the intermediate (I) hatch occurs from early to mid June; the late (L) hatch occurs from mid to late June; and the grasshoppers that overwinter in the nymph stage have a very late (VL) hatch that occurs from mid to late July.

The embryos of a single egg pod hatch together within several minutes. The nymphs wiggle to the soil surface, squirm out of an embryonic membrane cover, and are ready to start feeding. Most grasshopper species develop through five immature instar stages. The males of some grasshopper species develop through four instar stages. The females of a few large grasshopper species develop through six instar stages. Under typical environmental conditions, most grasshopper species develop from hatchling to adult stage in 35 to 50 days, at a rate of 7 to 10 days per instar.

The grasshopper nymph becomes an adult with the fifth or last instar molt. The new fledgling adult has fully functional wings, however, the reproductive organs are not fully developed. The young grasshoppers require a period of time, usually 1 to 3 weeks, to increase in weight and to complete maturation of reproductive organs. Adult males and females form mating pairs. After a period for egg development, the gravid female deposits a clutch of eggs in a hole below the soil surface in a bareground area. Most females are able to produce 4 to 25 egg pods with a total of 100 to 200 eggs during 50 to 75 days (Watts et al. 1989, Pfadt 1994, Cushing et al. 1996, Fisher et al. 1996a).

Grasshopper Diet

All grasshoppers are herbivorous and eat herbaceous plants. The grasshoppers that eat grasses are graminivorous. The grasshoppers that eat forbs are forbivorous. Many grasshoppers are mixed feeders and eat both grasses and forbs. Several of the nasty pestiferous grasshoppers are polyphagus and eat many different kinds of food plants including grasses, forbs, and agricultural crops. All of the substances necessary for growth, reproduction, and maintaining life processes in grasshoppers must come from the food plants that they eat.

Grasshoppers require a diet that provides adequate protein, energy, water, minerals, and vitamins. Protein is the most limiting nutrient. Protein makes up 50% of the cuticle of the exoskeleton. Muscle and organ tissue contain protein. Digestive enzymes and hemolymph (body fluid) require protein. Female ovarian growth and egg formation requires large amounts of the protein vitellogenin. Energy is obtained from simple sugars and soluble starches in plants. Grasshoppers do not require energy at the levels required by mammals. Grasshoppers are cold blooded (ectothermal) and do not regulate their body temperature metabolically. Available liquid water may be limiting in arid and semiarid regions that do not have dew in the morning. Water, then, must come from the food plants. The amount of water in the leaves of food plants could influence preference in dry habitats. Green grass leaves usually have high water content at 60% to 80%. The exoskeleton is efficient at conservation of water. Grasshopper requirements for macrominerals, microminerals, and vitamins is not known. The required amounts may vary but the types of vitamins and elemental minerals may be similar to those required by other living creatures. The quantity of nutrient intake and the allocation of ingested nutrients determines growth and development rates and reproductive production (Heidorn and Joern 1984, Joern 1996a, 1996b).

Grasshopper Digestive Tract

The digestive tract of grasshoppers is separated into three sections. The foregut (stomodaeum) consists of the mouth region. The maxillary and labial palpi are sensory organs that separate plant chemicals into attractants or repellants before the leaf is bitten. The manible cuts the leaf into bit size pieces and starts mechanical digestion. The salivary glands secrete chemical enzymes that digest carbohydrates.

The midgut (mesenteron) consists of the thorax and anterior segments of the abdomen region. The pharynx and esophagus are located in the buccal cavity and lead to the crop that holds food and starts protein digestion. The gizzard has hard tooth-like features that break up food. The stomach mixes chemical enzymes with the food to break it down. The gastric caecum surrounds the stomach, secretes digestive enzymes, protease, lipase, amylase, invertase, and several others, and absorbs amino acids. The peritrophic membrane continuously produces protein/chitin complex.

The hindgut (protodaeum) consists of the posterior segments of the abdomen region. The ileum section of the intestine continues food digestion and absorbs soluble food matter and water. The malpighian tubules excrete uric acid, urea, and amino acids into the rectum section of the intestine where dry pellets are formed from the food residue and waste products that are then disposed of through the anus (Joern 1996a, 1996b; Anonymous 2013).

Forage Nutritional Quality

Crude protein levels of cool season native range grasses are closely related to the phenological stages of growth and development, which are triggered primarily by the length of daylight. The length of daylight increases during the growing season between mid April and mid June (21 June) and then decreases. Lead tillers contain the highest levels of crude protein during the early stages of development. Cool season grasses are long day plants and the lead tillers usually reach the flower phenological stage before 21 June. Crude protein levels remain above 9.6% at flower stage but decrease rapidly during seed development and seed mature stages, dropping below 7.8% by early August and below 6.2% in late August (Whitman et al. 1951, Manske 2008a). Crude protein levels of cool season secondary tillers increase above 9.6% during July and August to 13.2% in early September, decrease during September, and drop below 9.6% in early to mid October (Sedivec 1999, Manske 2008a). Phosphorus levels of lead tillers drop below 0.18% in late July, when plants reach the mature seed stage (Whitman et al. 1951, Manske 2008b).

Crude protein levels of warm season native range grasses are closely related to the phenological stages of growth and development, which are triggered primarily by the length of daylight. Lead tillers contain the highest levels of crude protein during the early stages of development. Warm season grasses are short day plants and the lead tillers usually reach the flower phenological stage after 21 June. Crude protein levels remain above 9.6% at flower stage but decrease rapidly during seed development and seed mature stages, dropping below 9.6% in late July, and below 6.2% in early September (Whitman et al. 1951, Manske 2008a). Crude protein levels of warm season secondary tillers increase above 9.0% during August to 10.0% in early September, decrease during September, and drop below 9.6% in late September (Sedivec 1999, Manske 2008a). Phosphorus levels of lead tillers drop below 0.18% in late August, when plants reach the mature seed stage (Whitman et al. 1951, Manske 2008b).

Crude protein levels of upland sedges do not follow the same relationships with phenological growth stages as do the crude protein levels of cool and warm season grasses. Upland sedges contain the highest levels of crude protein during the early stages of development. Crude protein levels remain high through flower and seed mature stages and decrease with increases in senescence. Upland sedges grow very early and produce seed heads in late April to early May. Crude protein levels remain above 9.6% after seed mature stage, until mid July. Crude protein levels decrease below 7.8% in early August but do not fall below 6.2% for the remainder of the growing season (Whitman et al. 1951, Manske 2008a). Phosphorus levels drop below 0.18% in mid May, when plants reach the mature seed stage (Whitman et al. 1951, Manske 2008b).

The quality of grass forage available to grasshoppers on rangelands of the Northern Plains is above 9.6% crude protein in the lead tillers of the cool and warm season grasses during mid May to late July. Upland sedges have crude protein levels above 9.6% during early May to mid July. The secondary tillers of the cool and warm season grasses have crude protein levels above 9.6% during mid July to late September or mid October. All the grasses have adequate levels of energy throughout the growing season. Grasshoppers should be able to select a diet with adequate crude protein, energy, and water during early May through mid October from the upland sedges and the lead and secondary tillers of the cool and warm season grasses on the rangelands of the Northern Plains.

Grasshopper Forage Loss

All rangeland grasshoppers consume forage and reduce the quantity available for grazing livestock. Throughout western North America, grasshoppers annually destroy an estimated 21% to 23% of the available range forage (Hewitt and Onsager 1983, Onsager 1987). Only about 12% to 21% of the forage that grasshoppers clip from plants is consumed, the rest is discarded and permitted to drop to the ground as litter (Onsager 1987). The amount of forage consumed and destroyed by the typical low density grasshopper populations have automatically been incorporated into traditional regional stocking rates (Onsager 2000). These traditional stocking rate concessions are crude and grasshopper populations fluctuate with changes in management practices. The understanding of grasshopper biology has made great advancements and methods to calculate grasshopper forage loss have been developed (table 1). It is possible to determine the quantity of forage loss in specific rangeland pastures and to adjust the stocking rate appropriately. The quantity of rangeland forage loss caused by grasshoppers can be determined from the grasshopper species average dry weight and their density.

The regional APHIS cooperative control programs for rangeland grasshoppers traditionally required an average density of $8/yd^2$ ($9.6/m^2$) as the guideline to activate liquid insecticide control treatments. Some of the treatment costs were greater than the value of the forage saved (Onsager 1984). The density count of the grasshopper population alone does not give a valid number for the quantity of forage losses (Hewitt, Burleson, and Onsager 1976). A quantitative assessment of grasshopper caused forage losses needed to be developed to determine the amount of forage destroyed, both the forage consumed along with the forage clipped and let fall to the ground, by each individual grasshopper species (Hewitt, Burleson, and Onsager 1976). The quantity of forage consumed and destroyed by grasshoppers is difficult to determine and is highly variable because of grasshopper species composition, stage of development, and rate of survival (Onsager 1984).

The standard amount of forage destroyed (consumed and wasted) by nymphs was determined from field data collected for *Amphitorus coloradus* and *Camnula pellucida* nymphs from hatching to the adult stage. The total quantity of forage destroyed by the nymphs was divided by the mean total adult dry weight to obtain a nymphal feeding ratio of 4.5 (Hewitt and Onsager 1982a). The standard amount of forage destroyed per day by adults was determined from field data collected for *Melanoplus sanguinipe*s, *Melanoplus infantilis*, *Melanoplus foedus*, and *Aulocara elliotti*. The quantity of forage destroyed per day by the adults was divided by the average dry weight of the adults to obtain the mean adult feeding ratio of 0.65 (Hewitt and Onsager 1982a).

Forage losses (consumed and destroyed) are directly proportional to grasshopper size (Hewitt and Onsager 1982a). Grasshopper species can be divided into 3 size classes using two criteria: the **small size** grasshopper has mean male-female dry weight at less than 65 mg, and female dry weight at less than 100 mg; the **medium size** grasshopper has mean male-female dry weight between 66 mg and 120 mg, and female dry weight from 100 mg to 200 mg; and the **large size** grasshopper has mean male-female dry weight at greater than 120 mg, and female dry weight at greater than 200 mg.

Grasshoppers have 6 stages of development with 5 nymphal instar stages and the adult stage. Because of differences in size, each of the development stages consumes and destroys different amounts of forage. Each immature instar stage requires 7 to 10 days for development; with 5 instar stages, the nymphal period is usually 35 to 50 days long. The first 3 instar stages are responsible for about 15%-20% of the total forage loss caused by a generation of grasshoppers (Onsager 1984). The greatest forage loss occurs during the 4^{th} and 5^{th} instar stages and the adult stage (Hewitt and Onsager 1982a). The period of development during the 4^{th} and

5th instar stages has usually been 7 days each (Hewitt and Onsager 1982a, 1983; Onsager 1987). After fledging, the adult grasshoppers become sexually mature in 10 to 14 days (Hewitt and Onsager 1983). The average life span of a grasshopper is 46 days (Hewitt and Onsager 1982a). The longevity of adult grasshoppers is highly variable from 32 days (Hewitt and Onsager 1982a), to 77 days (Hewitt and Onsager 1983), and up to 90 days (Onsager 1983, 1984). The maximum grasshopper longevity from hatch to death can be 109 days (Onsager 1983), 112 days (Hewitt and Onsager 1983), or 135 days (Onsager 1984).

Grasshopper species within multispecies populations have different mortality rates (Onsager 1987). Grasshoppers with daily survival rates between 0.95 and 0.96 will be able to maintain populations with only slight changes from season to season. Grasshoppers with survival rates of 0.93 or lower would have sharp reductions in their populations. Grasshoppers with daily survival rates of 0.97 or greater would have population growth and could reach outbreak levels within a minimum of two generations (Onsager 1983). The mortality rates for grasshopper species per year in natural populations have wide ranges from 2% to 13% for nymphs and from 3% to 40% for adults (Onsager 1987).

The quantity of grasshopper caused forage loss can be determined for each species from the dry weights of the 4th and 5th instar stages and the mean male-female dry weight of the adult stage (Hewitt and Onsager 1982a), or by the separate adult dry weight of the males and the females. A method that calculates forage losses caused by grasshoppers has been developed by Hewitt and Onsager (1982a). The method determines the forage loss during the 4th and 5th instar stages for 7 days each and during the adult stage for 32 days. The total forage loss for 46 days or the mean forage loss per day (mg/d) are the methods products. An addition step can be performed that converts the forage loss per day (mg/d) into pounds of forage loss per acre per month (lbs/ac/mo) for one grasshopper per square yard ($1/yd^2$) over one acre (table 1).

Forage loss caused by the pestiferous rangeland grasshoppers in the Northern Plains in milligrams per day (mg/d) and pounds per acre per month (lbs/ac/mo) have been determined (table 2). The mean milligrams per day forage loss was 27.4 mg/d, 53.11 mg/d, and 99.76 mg/d for the small, medium, and large grasshoppers, respectively (table 2). The mean pounds per acre per month forage loss was 8.92 lbs/ac/mo, 17.28 lbs/ac/mo, and 32.46 lbs/ac/mo for the small, medium, and large grasshoppers, respectively (table 2).

The forage loss amount in pounds per acre per month (lbs/ac/mo) for each grasshopper species from table 2 can be multiplied by various grasshopper densities to determine the greater quantities of forage losses as the population increases. In addition, the mean forage loss per day (mg/d) for the adults of each grasshopper species (step C, table 1) can be converted into pounds of forage loss per acre per month (lbs/ac/mo) (step E). This forage loss in pounds per acre per month for just the adults can be added to the forage loss for the 4th and 5th instar stages and the adult stage to determine the combined total forage loss during 2 or 3 months (61 days or 92 days) for a grasshopper density of one per square yard over one acre. To determine the greater quantities of forage losses as the population increases, the 2 and 3 month forage loss values for 1 grasshopper can be multiplied by various other grasshopper densities.

Forage consumed and destroyed by pestiferous rangeland grasshoppers in pounds per acre (lbs/ac) from hatch to death for 21 days of the early instar stages, the 1st, 2nd, and 3rd months of the late instar stages and the adult stages with a 112 day longevity at a density of one grasshopper per square yard ($1/yd^2$) per acre have been determined (table 3). The mean pounds per acre forage loss was 33.54 lbs/ac, 64.86 lbs/ac, and 122.79 lbs/ac for small, medium, and large grasshoppers at one per square yard, respectively (table 3). The greater quantities of forage loss caused by increased populations can be determined by multiplying the forage loss in lbs/ac at a grasshopper density of $1/yd^2$ by other grasshopper densities.

Rather than make these forage loss calculations for each of the 400 rangeland grasshopper species in North America, rangeland entomologists have chosen to develop a theoretical average rangeland grasshopper (Hewitt and Onsager 1982a, 1983; Onsager 1984, 1987). The quantity of forage losses caused by the theoretical average grasshopper can be used to estimate the economic significance of any grasshopper infestation, of any density, on any grasshopper habitat (Onsager 1987).

The average rangeland grasshopper infestation has been comprised of 40% small size, 55% medium size, and 5% large size grasshoppers (Hewitt and Onsager 1982a). A composite average grasshopper was developed with the data from the small size grasshoppers, *Ageneotettix deorum* and

Melanoplus infantilis; the medium size grasshoppers, *Aulocara elliotti* and *Melanoplus sanguinipes*; and the large size grasshopper, *Melanoplus bivittatus* (Onsager 1984).

The composited theoretical average rangeland grasshopper consists of 40% small size, 55% medium size, and 5% large size grasshopper. The average dry weight of the 4th instar, 5th instar, and mean male-female adult is 19.2 mg, 45.3 mg, and 81.6 mg, respectively, and the quantity of forage consumed and destroyed is 9 mg, 22 mg, and 53 mg per day, respectively (Onsager 1984). The amount of forage consumed and wasted by grasshoppers tends to increase with the increasing stages of development (Hewitt and Onsager 1983). The daily rate of forage loss per average grasshopper increases 2.42 times with each successive instar (Onsager 1983).

The forage loss (consumed and destroyed) caused by the average rangeland grasshopper can be calculated by the steps of the forage loss method developed by Hewitt and Onsager (1982a) and explained in detail by Onsager (1983, 1984, 1987) (table 1). The average grasshopper 4th instar stage dry weight is 19.2 mg and in 7 days it destroys 79.49 mg of forage (step A). The average grasshopper 5th instar stage dry weight is 45.3 mg and in 7 days it destroys 156.96 mg of forage (step B). The average grasshopper adult stage dry weight is 81.6 mg and in 32 days it destroys 1697.28 mg of forage at a rate of 53 mg/d (step C). The average grasshopper destroys 79.49 mg as a 4th instar, destroys 156.96 mg as a 5th instar, and destroys 1697.28 mg as an adult for a total of 1933.73 mg of forage destroyed in 46 days at an average rate of 42.04 mg of forage loss per day (step D). The average forage loss of 42.04 mg/d converts into an average forage loss of 13.7 lbs/ac/mo (step E). Which means that one grasshopper at a density of 1/yd^2 over 1 acre destroys an average of 13.7 pounds of forage per acre per month. Economic value of the annual forage loss caused by grasshoppers is used to determine cost-benefit ratio for the chemical insecticide treatment costs.

The average adult grasshopper can live for 1 or 2 additional months (Onsager 1983, 1984). The forage loss during these 1 or 2 additional months can be calculated from the average adult grasshopper forage loss of 53 mg/d. The average forage loss of 53 mg/d converts into an average forage loss of 17.25 lbs/ac/mo (step E). The average rangeland grasshopper destroys forage during the first month at 13.7 lbs/ac/mo, destroys forage during the second month at 17.25 lbs/ac/mo, and destroys forage during the third month at 17.25 lbs/ac/mo with the total quantity of forage destroyed after two months of 30.95 lbs/ac, and with the total quantity of forage destroyed after three months of 48.2 lbs/ac by 1 grasshopper per square yard on one acre. The greater quantities of forage loss caused by increasing populations can be determined by multiplying the forage loss in lbs/ac/mo for 1/yd^2 density by other grasshopper densities. The average grasshopper at densities of 4/yd^2 causes forage losses of 123.8 lbs/ac after two months and 192.8 lbs/ac after three months. The average grasshopper at densities of 8/yd^2 causes forage losses of 247.6 lbs/ac after two months and 385.6 lbs/ac after three months. Rangeland forage allocation for a 1000 pound cow with a calf is 793 pounds per month.

Grasshopper Ecosystem Degradation

The losses caused by grasshopper feeding should not be evaluated only in terms of the quantity of forage consumed and destroyed. The green leaf material cut and discarded by feeding grasshoppers is not beneficial litter; the loss of this photosynthetically active tissue causes debilitating changes in growing grass tillers. Grasshopper defoliation adversely affects grass plant growth and development. The reductions of grass photosynthetic area decreases herbage biomass production causing reductions in total weight of the leaves, crowns, roots, and rhizomes, decreasing the root depth, and greatly reducing the number of secondary tillers produced (Burleson and Hewitt 1982).

The severity of the detrimental effects on grass plants from grasshopper defoliation will depend on the degree of foliage removal and the phenological growth stage of the grass tillers. The primary period of growth in grass leaf and flower stalk height and the accumulation in aboveground herbage weight occurs during the remarkably short period of May, June, and July, which coincides with the period of greatest precipitation, at 51% of the annual quantity. Cool season grasses complete 100% of their growth in leaf and flower stalk height by 30 July. Warm season grasses complete 100% of their growth in leaf height and 91% of their growth in flower stalk height by 30 July; a small amount of flower stalk elongation continues until 30 August (Goetz 1963). Peak aboveground herbage biomass is reached during the last 10 days of July. After the end of July, herbage weight decreases because the rate of senescence of the grass leaves exceeds the rate of growth (Manske 2000a).

Grass plants that have flowered and reached their maximum leaf and flower stalk height can tolerate removal of up to 50% of the aboveground plant material. Severe defoliation by large grasshopper infestations that remove greater than 50% of the leaf material results in insufficient leaf area retained on the tiller for even partial foliage recovery using current photosynthetic assimilates. Tillers with 50% or more of the aboveground leaf material removed reduce root growth, root respiration, and root nutrient absorption (Crider 1955). Root mortality and decomposition begin within 2 days of severe leaf defoliation (Oswalt et al. 1959). There is a high biological cost to the tiller when the photosynthetic system needs to be replaced from stored carbohydrates (Briske and Richards 1995). This reduction in efficiency results in reduced root growth, decreased tiller development, and low growth rates causing decreased tiller numbers, reduced total basal area, and reduced quantites of herbage biomass produced (Coyne et al. 1995).

Prior to peak herbage biomass, grass plants cannot tolerate defoliation of 50% of the aboveground herbage biomass because removal of that much leaf material deprives tillers of foliage needed for photosynthesis. Grass tillers at phenological growth between the 3.5 new leaf stage and flower (anthesis) stage do well with partial defoliation that removes 25% to 33% of the leaf material. Defoliation that removes 50% of the leaf material after the 3.5 new leaf stage and before the flower stage suppresses secondary tiller development 52.9% below nondefoliated tillers (Manske 2003) and replacement leaf weight is 29.2% less than the weight of the leaf material removed (Manske 2000b).

Grasshopper defoliation of grass tillers prior to the 3.5 new leaf stage is devastating to grass tiller growth and development. Spring growth of grass tillers depends both on carbohydrate reserves and on photosynthetic products from the portions of previous years leaves that overwintered without cell wall rupture and regreened with chlorophyll. Grass growth requires that the tiller maintains adequate leaf area with a combination of carryover leaves and new leaves to provide photosynthetic product for growth of sequential new leaves until the tiller produces 3.5 new leaves. Little spring leaf growth is produced from stored nonstructural carbohydrates because most of the reserves are reduced during the winter respiration period (Coyne et al. 1995). After the 3.5 new leaf stage, the new leaves provide adequate photosynthetic product for subsequent new leaf growth (Manske 2011b).

The critical grass tiller development period prior to the 3.5 new leaf stage for cool and warm season native grasses occurs during 15 May to 21 June. Native grass species do not reach the 3.5 new leaf stage at the same time. Some early native cool season grasses produce the 3.5 new leaf by early June and most native warm season grasses produce the 3.5 new leaf by 21 June.

Several rangeland grasshoppers of the Northern Plains have developmental phenology that overlap with the critical grass tiller development period (table 4). The hatching period of these ecosystem degrading pestiferous grasshoppers is with the very early and early groups starting in late April to mid May. All of these grasshoppers have fledged into the adult stage before the end of the critical grass tiller period (table 4).

During the 38 day critical grass tiller period, the 4th and 5th instar and adult stages of these pestiferous grasshoppers, at densities of 1/yd^2 over 1 acre, consume and destroy an average of 9.5 lbs/ac of grass leaves (table 5). At densities of 8/yd^2 over 1 acre, these grasshoppers would consume and destroy an average of 76.2 lbs/ac of grass leaves.

Premature grasshopper defoliation of grass tillers before production of the 3.5 new leaf could result in greatly reduced growth rates of herbage production (Coyne et al. 1995) causing decreased peak herbage biomass late in the growing season with possible reductions of 45% to more than 75% of the potential herbage biomass (Campbell 1952, Rogler et al. 1962, Manske 2000b).

Ecosystem degradation does not occur instantaneously and usually does not show significant differences for 2 to 3 years after initiation. Grasshoppers that increase to moderate outbreak levels, hatch very early and early, and develop through the 4th and 5th instar stages and adult stage during periods when grass growth is rapid and when soils usually have adequate water consume and destroy leaves of grass tillers before they develop 3.5 new leaves cause ecosystem degradation. Ecosystem degradation results in long term economic losses.

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Table 1. Methods to determine forage loss from pestiferous rangeland grasshoppers.

The forage loss methods were developed by Hewitt and Onsager 1982a.

The quantity of forage loss as milligrams per day (mg/d) and pounds per acre per month (lbs/ac/mo) caused by 1 grasshopper is based on mean grasshopper dry weight in milligrams (mg) at the 4^{th} instar for 7 days, the 5^{th} instar for 7 days, and the adult stage of male, female, or mean of both for 32 days.

A. Grasshopper 4^{th} instar dry weight (mg) X 4.5 feeding ratio X 0.92 mortality rate = forage loss (mg) for 7 days.

B. Grasshopper 5^{th} instar dry weight (mg) X 4.5 feeding ratio X 0.77 mortality rate = forage loss (mg) for 7 days.

C. Adult grasshopper dry weight (mg) for male, female, or mean of both X 0.65 feeding ratio = forage loss (mg) per day X 32 days = total forage loss from adult for 32 days.

D. 4^{th} instar forage loss for 7 days + 5^{th} instar forage loss for 7 days + adult forage loss for 32 days = total forage loss by 1 grasshopper for 46 days ÷ 46 days = mean forage loss by 1 grasshopper for 1 day in milligrams per day (mg/d).

Conversion of forage loss from 1 grasshopper in milligrams per day (mg/d) into forage loss in pounds per acre per month (lbs/ac/mo) from a population density of 1 grasshopper per square yard ($1/yd^2$) over an area of 1 acre for a period of 1 month with 30.5 days.

E. Forage loss in mg/d from 1 grasshopper X 4840.0 yd^2/ac ÷ 1000 mg/g X 0.03527 oz/g X 0.0625 oz/lb X 30.5 d/mo = forage loss from 1 grasshopper per square yard per acre ($1/yd^2$/ac) in pounds per acer per month (lb/ac/mo).

Methods from Hewitt and Onsager 1982a, Onsager 1983, 1984, 1987.
30.5 days per grazing season month from Manske 2012a.

Table 2. Forage loss from pestiferous rangeland grasshoppers (one/yd^2) in mg/d and lbs/ac/mo based on mean grasshopper dry weight (mg).

Pestiferous Rangeland Grasshoppers	Sex	Mean dry weight (mg) for one grasshopper			Forage consumed & destroyed by one grasshopper/yd^2	
		4th instar	5th instar	Adult	mg/d	lbs/ac/mo
Small size grasshoppers with females at < 100 mg						
Aeropedellus clavatus	mean	10.7	22.2	45.8	23.34	7.60
Ageneotettix deorum	mean	11.8	27.4	60.0	30.26	9.85
	male			31.0	17.14	5.58
	female			89.0	43.37	14.11
Amphitornus coloradus	mean	19.3	38.0	60.5	31.96	10.40
	male			41.0	22.85	7.44
	female			80.0	40.77	13.27
Cordillacris occipitalis	mean	10.6	12.7	48.5	23.84	7.76
	male			30.0	15.48	5.04
	female			67.0	32.21	10.48
Melanoplus infantilis	mean	12.5	28.1	58.0	29.47	9.59
	male			53.0	27.21	8.85
	female			63.0	31.72	10.32
Opeia obscura	mean	10.6	12.7	34.5	17.51	5.70
	male			21.0	11.41	3.71
	female			48.0	23.62	7.69
Phlibostroma quadrimaculatum	mean	14.0	20.6	62.5	31.07	10.11
	male			35.0	18.64	6.07
	female			90.0	43.51	14.16
Trachyrhachys kiowa	mean	18.8	26.7	62.0	31.74	10.33
	male			44.0	23.60	7.68
	female			80.0	39.88	12.98

Table 2 cont. Forage loss from pestiferous rangeland grasshoppers (one/yd^2) in mg/d and lbs/ac/mo based on mean grasshopper dry weight (mg).

Pestiferous Rangeland Grasshoppers	Sex	Mean dry weight (mg) for one grasshopper			Forage consumed & destroyed by one grasshopper/yd^2	
		4th instar	5th instar	Adult	mg/d	lbs/ac/mo
Medium size grasshoppers with females at 100 mg to 200 mg						
Aulocara elliotti	mean	20.4	45.6	98.0	49.58	16.13
	male			52.0	28.78	9.37
	female			144.0	70.38	22.90
Aulocara femoratum	mean	20.4	45.6	89.5	45.74	14.88
	male			42.0	24.26	7.89
	female			137.0	67.22	21.87
Camnula pellucida	mean	20.4	45.6	80.0	41.44	13.48
	male			55.0	30.14	9.81
	female			105.0	52.75	17.17
Encoptolophus costalis	mean	22.9	67.9	92.5	49.00	15.95
	male			50.0	29.78	9.69
	female			135.0	68.22	22.20
Eritettix simplex	mean	20.4	45.6	71.5	37.60	12.24
	male			33.0	20.19	6.57
	female			110.0	55.01	17.90
Melanoplus confusus	mean	18.4	37.6	117.2	57.48	18.70
Melanoplus femurrubrum	mean	22.7	83.7	106.5	56.50	18.39
	male			87.0	47.69	15.52
	female			126.0	65.32	21.26
Melanoplus gladstoni	mean	36.1	62.0	130.5	66.93	21.78
	male			127.0	65.35	21.27
	female			134.0	68.51	22.29

Table 2 cont. Forage loss from pestiferous rangeland grasshoppers (one/yd^2) in mg/d and lbs/ac/mo based on mean grasshopper dry weight (mg).

Pestiferous Rangeland Grasshoppers	Sex	Mean dry weight (mg) for one grasshopper			Forage consumed & destroyed by one grasshopper/yd^2	
		4th instar	5th instar	Adult	mg/d	lbs/ac/mo
Melanoplus occidentalis	mean	19.2	31.8	130.0	62.91	20.47
	male			86.0	43.01	14.00
	female			174.0	82.80	26.94
Melanoplus sanguinipes	mean	22.9	52.0	131.5	65.44	21.29
	male			112.0	56.62	18.42
	female			151.0	74.26	24.16
Phoetaliotes nebrascensis	mean	23.8	56.4	100.0	51.61	16.79
	male			63.0	34.88	11.35
	female			137.0	68.34	22.24
Large size grasshoppers with females at > 200 mg						
Melanoplus bivittatus	mean	47.6	147.2	253.5	129.99	42.30
	male			166.0	90.43	29.43
	female			341.0	169.56	55.18
Melanoplus differentialis	mean			no data		
Melanoplus packardii	mean	35.4	93.1	174.5	89.10	28.99
	male			141.0	73.96	24.07
	female			208.0	104.25	33.92
Metator pardalinus	mean	22.4	38.7	166.5	80.20	26.10
	male			97.0	48.78	15.87
	female			236.0	111.63	36.33

Dry weight of 4th and 5th instar from Hewitt and Onsager 1982a.
Dry weight of adult male and female from Pfadt 1994.
Methods follow Hewitt and Onsager 1982a and shown in table 1.

Table 3. Forage consumed and destroyed in pounds per acre by one grasshopper per square yard per acre from first instar to old adult.

Pestiferous Rangeland Grasshoppers	Hatch Period	1st-3rd Instar	4th-5th Instar Flegling Adult	Reproductive Adult	Senior Mature Adult	Combined 1st Instar to Old Adult
		21 days 0.7 month	30.5 days 1st month	30.5 days 2nd month	30.5 days 3rd month	112.5 days 3.7 months
Small size grasshoppers with females at < 100 mg						
Aer cla	VE	1.52	7.60	9.69	9.69	28.50
Age deo	E	1.97	9.85	12.69	12.69	37.20
Amp col	E	2.08	10.40	12.80	12.80	38.08
Cor occ	E	1.55	7.76	10.26	10.26	29.83
Mel inf	E	1.92	9.59	12.27	12.27	36.05
Ope obs	L	1.14	5.70	7.30	7.30	21.44
Phl qua	I	2.02	10.11	13.22	13.22	38.57
Tra kio	I	2.07	10.33	13.11	13.11	38.62
Medium size grasshoppers with females at 100 mg to 200 mg						
Aul ell	E	3.23	16.13	20.73	20.73	60.82
Aul fem	I	2.98	14.88	18.93	18.93	55.72
Cam pel	E	2.70	13.48	16.92	16.92	50.02
Enc cos	I	3.19	15.95	19.56	19.56	58.26
Eri sim	VL	2.45	12.24	15.12	15.12	44.93
Mel con	VE	3.74	18.70	24.79	24.79	72.02
Mel fem	I	3.68	18.39	22.53	22.53	67.13
Mel gla	L	4.36	21.78	27.60	27.60	81.34
Mel occ	E	4.09	20.47	27.50	27.50	79.56
Mel san	E	4.26	21.29	27.81	27.81	81.17
Pho neb	L	3.36	16.79	21.15	21.15	62.45

Table 3 cont. Forage consumed and destroyed in pounds per acre by one grasshopper per square yard per acre from first instar to old adult.

Pestiferous Rangeland Grasshoppers	Hatch Period	1^{st}-3^{rd} Instar	4^{th}-5^{th} Instar Flegling Adult	Reproductive Adult	Senior Mature Adult	Combined 1^{st} Instar to Old Adult
		21 days 0.7 month	30.5 days 1^{st} month	30.5 days 2^{nd} month	30.5 days 3^{rd} month	112.5 days 3.7 months
Large size grasshoppers with females at > 200 mg						
Mel biv	E	8.46	42.30	53.62	53.62	158.00
Mel dif	I			No data		
Mel pac	E	5.80	28.99	36.91	36.91	108.61
Met par	I	5.22	26.10	35.22	35.22	101.76
Composited theoretical 40% small, 55% medium, and 5% large size rangeland grasshopper						
Standardized		2.74	13.70	17.25	17.25	50.94

Table 4. Pestiferous rangeland grasshopper developmental phenology overlap with cool and warm season grass critical development period prior to 3.5 new leaf stage during 15 May to 21 June.

Pestiferous Rangeland Grasshoppers	Grasshopper Developmental Phenology
Aeropedellus clavatus, Clubhorned Grasshopper,	hatch in early May, develop rapidly through the 3rd instar stage, are in the 4th/5th instar stage for 7 days, and are in the adult stage for 23 days during the critical grass period.
Aulocara elliotti, Bigheaded Grasshopper,	hatch in mid May, develop through the 1st, 2nd, and 3rd instar stages, are in the 4th/5th instar stage for 10 days, and are in the adult stage for 6 days during the critical grass period.
Cordillacris occipitalis, Spottedwinged Grasshopper,	hatch in mid May, develop through the 1st, 2nd, and 3rd instar stages, are in the 4th instar stage for 7 days, are in the 5th instar stage for 7 days, and are in the adult stage for 2 days during the critical grass period.
Eritettix simplex, Velvetstriped Grasshopper,	overwinter in a late instar stage and are in the adult stage for 38 days during the critical grass period.
Melanoplus confusus, Pasture Grasshopper,	hatch in late April, are in the late 4th instar stage for 4 days, are in the 5th instar stage for 7 days, and are in the adult stage for 27 days during the critical grass period.
Melanoplus infantilis, Little Spurthroated Grasshopper,	hatch in late May, develop rapidly through the 1st, 2nd, and 3rd instar stages, are in the 4th instar stage for 5 days, are in the 5th instar stage for 5 days, and are in the adult stage for 8 days during the critical grass period.
Melanoplus occidentalis, Flabellate Grasshopper,	hatch in mid May, develop through the 1st, 2nd, and 3rd instar stages, are in the 4th instar stage for 7 days, are in the 5th instar stage for 7 days, and are in the adult stage for 2 days during the critical grass period.

Table 5. Leaf weight loss (mg and lb/ac) during the critial 38 day period, 15 May to 21 June, of grass tiller development prior to 3.5 new leaf stage from pestiferous rangeland grasshoppers at a density of one/yd^2.

Pestiferous Rangeland Grasshoppers		4th instar		5th instar	Adult	Total	lb/ac/d
Aeropedellus clavatus	days		7		23	30	
	dry wt		22.2		45.8		
	mg		76.92		684.71	761.63	
	lb/ac		0.82		7.31	8.13	0.27
Aulocara elliotti	days		10		6	16	
	dry wt		33.0		98.0		
	mg		126.23		382.20	508.43	
	lb/ac		1.35		4.08	5.43	0.39
Cordillacris occipitalis	days	7		7	2	16	
	dry wt	10.6		12.7	48.5		
	mg	43.88		44.01	63.05	150.94	
	lb/ac	0.47		0.47	0.67	1.61	0.10
Eritettix simplex	days				38	38	
	dry wt				71.5		
	mg				1766.05	1766.05	
	lb/ac				18.84	18.84	0.50
Melanoplus confusus	days	4		7	27	38	
	dry wt	18.4		37.6	117.2		
	mg	63.76		130.28	2056.86	2250.90	
	lb/ac	0.68		1.39	21.94	24.01	0.63
Melanoplus infantilis	days	5		5	8	18	
	dry wt	12.5		28.1	58.0		
	mg	51.75		97.37	301.60	450.72	
	lb/ac	0.55		1.04	3.22	4.81	0.27
Melanoplus occidentalis	days	7		7	2	16	
	dry wt	19.2		31.8	130.0		
	mg	79.49		110.19	169.00	358.68	
	lb/ac	0.85		1.18	1.80	3.83	0.24

Dry weight of 4th and 5th instar from Hewitt and Onsager 1982a.
Dry weight of mean adult from Pfadt 1994.
Methods follow Hewitt and Onsager 1982a and shown in table 1.

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