Orchard Groundcover Management Systems Affect Meadow Vole Populations and Damage to Apple Trees

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Abstract. Meadow vole (*Microtus pennsylvanicus* Ord) populations, feeding activity and damage to young apple (*Malus ×domestica* Borkh.) trees were monitored for several years in a New York orchard by direct observation, trap counts, and a feeding activity index in various groundcover management systems (GMSs). Meadow vole population density differed among GMSs, with consistently higher densities and more trees damaged in crown vetch (*Coronilla varia* L.), hay-straw mulch, and red fescue (*Festuca rubra* L.) turfgrass tree-row strips. Vole densities were high in autumn and low in spring each year. Anticoagulant rodenticides and natural predation did not adequately control voles in GMSs providing favorable habitat. Groundcover biomass per m² was weakly correlated with vole densities in 2 of 3 years, while the percentage of soil surface covered by vegetation was not significantly correlated with vole populations. Applications of thiram fungicide in white latex paint were better than no protection, but less effective than 40-cm-high plastic-mesh guards for preventing vole damage to tree trunks. A combination of late-autumn trapping, close and consistent mowing of the orchard floor, trunk protection with mesh guards, contiguous habitat for vole predators, and herbicide applications within the tree rows provided effective control of meadow-vole damage to trees at this orchard during 3 years without applications of rodenticide baits. Chemical names used: Tetramethylthiuram disulfide (thiram)

Short-tailed rodents known as field mice or voles (*Microtus* sp.) often cause serious damage in North American orchards (Byers, 1984). Meadow and pine voles (*M. pinetorum* Leconte) are especially problematic in apple orchards of the eastern United States, where their economic damage has been estimated at \$US 40 to 50 million annually (Byers, 1984; La Voie and Teitjen, 1978), and annual costs of damage and controls often exceed \$100 per ha (Phillips et al., 1987). Voles consume the bark, phloem, cambium, and outer xylem of large roots, crown and lower trunks, injuring and sometimes killing trees. Damage is most frequent in the dormant season from late fall to early spring, when other food sources are relatively scarce and snow cover protects foraging voles from avian and mammalian predators (Byers, 1984; Madison et al., 1984).

Habitat management and rodenticide baits are the primary methods for controlling voles in orchards. Chemical controls involve placement of anticoagulant rodenticides such as chlorophacinone, or acutely toxic baits such as zinc phosphide, in nesting and feeding sites after apple harvest when vole populations are typically highest (Byers et al., 1982; Taitt and Krebs, 1985). A few voles often develop “bait shyness” after sublethal exposures to acute toxicants; thus poison baits rarely provide complete control of these rodents (Byers et al., 1982). Secondary poisonings of raptors and other predators by eating voles that have ingested some anticoagulant rodenticides have also been reported (Merson et al., 1984). Integrating orchard soil and groundcover management systems with rodenticide applications is therefore necessary for effective control of voles.

Voies form large nesting colonies and food caches in sheltered areas such as brush piles, thick mulches, and matted or nonmown groundcover vegetation (Byers and Young, 1978). Orchard groundcover management systems (GMSs) that deprive voles of shelter and expose them to predators help suppress these pests (Madison et al., 1983). Herbicide applications or mechanical cultivation that minimize surface vegetation beneath fruit trees can reduce but not eliminate vole damage, and also promote optimal tree growth and fruit production (Byers, 1984; Hogue and Neilsen, 1987;

Smallwood, 1996). Despite the economic impacts of vole damage in orchards, the relative importance and influence of different GMSs on meadow voles are not fully understood, and they remain a common problem for apple growers. Our objectives in this research were: 1) to examine the influence of different GMSs on meadow vole population densities and tree damage during several consecutive years; and 2) to evaluate quantitative aspects of vole habitat such as herbicide strip widths, and above-ground vegetation biomass or soil surface coverage as predictors for vole densities and damage.

Materials and Methods

The experiment was established in a newly planted apple orchard at Ithaca N.Y., surrounded by older orchards on three sides and a nonmowed pasture on the west edge. Alternate rows of ‘Empire’ and ‘Jonagold’ apple on ‘MM.111’ rootstocks were planted in Apr. 1986, spaced at 3 m within and 6 m between rows. Eight GMS treatments were randomly assigned and established in the tree-rows as 25-m-long by 1.5- or 2.5-m-wide plots containing eight adjacent apple trees. Each tree row contained a single GMS treatment, arranged in 48 parallel but noncontiguous plots, each separated by mowed grass driveways 3.5 m wide. There were six blocked replications of eight GMS treatments: 1) CNVCH—a 2.5-m-wide leguminous groundcover of ‘Penngriff’ crownvetch; 2) GLY1.5—a 1.5-m-wide strip where vegetation was suppressed with applications of glyphosate [*N*-(phosphonomethyl) glycine] herbicide at the rate of 2 kg·ha⁻¹, in May and July each year; 3) GLY2.5—a 2.5-m-wide glyphosate treated strip; 4) NDPQT—a 2.5-m-wide strip kept free of surface vegetation with annual applications of norflurazon [4-chloro-5-methylamino-2-(3-(trifluoromethyl) phenyl)-3(2*H*)-pyridazinone], diuron [*N*-(3,4-dichlorophenyl)-*N*, *N*-dimethylurea], and paraquat (1,1′-dimethyl-4,4′-bipyridinium ion) herbicides, applied in mid-May each year at 3.0, 2.5, and 0.5 kg·ha⁻¹ a.i., respectively; 5) MWSOD—a turfgrass mixture of predominantly ‘Ensylva’ red fescue, mowed to 6-cm height at monthly intervals during each growing season; 6) GRSOD—a 2.5-m-wide strip of red fescue chemically suppressed in May and July each growing season with sublethal applications of glyphosate (0.2 kg·ha⁻¹ a.i.); 7) STMCH—a 2.5-m-wide hay-straw mulch strip renewed each May to 15-cm depth (≈30 kg of mulch per tree); and 8) TILLED—a 2.5-m-wide clean-cultivated strip maintained by rototilling to 8-cm depth monthly from May through August each year.

For the first 4 years after planting in 1986, all tree trunks were surrounded with 20-cm-high metal-mesh guards, and anticoagulant rodenticide (chlorophacinone) bait-dispensing stations (T-shaped, 5-cm-diameter, PVC pipes) were maintained year round at the center of each GMS plot. Despite these precautions, vole damage was first observed on trees in some plots during 1987, and then extensive damage occurred on trees in CNVCH and

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STMCH plots in Oct. 1989. Anticoagulant bait stations were removed in Nov. 1989, and zinc-phosphide impregnated grain rodenticide was applied throughout the orchard. At this point intensive monitoring of meadow vole population trends was begun in each GMS. From Dec. 1989 until Dec. 1992, rodenticide baits were discontinued at the site, and we used two sequential sampling methods to monitor vole feeding activity and population dynamics. Feeding activity indices were determined during 3-day periods in the spring, summer, and fall seasons from 1990 to 1992, by placing half slices of 'Empire' apple beneath asphalt roofing shingles (30 × 30 cm) in each plot, and recording the proportion of each slice that was gnawed or eaten by rodents (Byers, 1975). After these feeding activity indices were determined, voles were captured alive with baited boxtraps (Sherman Traps, Tallahassee, Fla.) in each GMS plot, marked by toe clipping (for subsequent identification if recaptured) and then released, during three consecutive days in Apr. and July 1991, and again in May and July 1992. Finally, in Nov. 1990, 1991, and 1992, meadow voles were trapped, counted, and killed in each GMS plot.

We conducted a split-plot experiment in the same orchard to test the effectiveness of thiram fungicide, which was registered for trunk application on fruit trees as a rodent feeding repellent (Swihart, 1990). Three lower trunk treatments were randomly assigned to one of three adjacent trees in the center of each GMS plot: 1) painting the lower 35 cm of tree trunks with thiram 42-S formulation diluted at 10% (v/v) in a flat white latex paint; 2) surrounding the trunk with 40-cm high plastic-mesh cylindrical guards at ground level; and 3) leaving the lower trunk without protection. The remaining five trees in each plot were also protected with 40-cm-high plastic-mesh guards. Meadow vole feeding on lower trunks and root crowns of the three selected trees was assessed visually at each subsequent population census, and recorded as the percentage of rootstock or scion bark circumference damaged by gnawing. We also continued to assess annually the proportion of all trees in each GMS sustaining visible rodent damage since the previous year's observations.

Above-ground biomass of overwintering surface vegetation was estimated in early Oct. 1989, by randomly sampling a 0.5-m² clip quadrat in each plot, sorting and identifying the groundcover species in each sample, and determining specific and total fresh weights. The inert hay-straw mulch material was not included in these samples, but live vegetation growing in or through the STMCH was included. Surface vegetation coverage was also estimated as the percentage of total soil surface covered in each plot during mid-October from 1986 to 1989, using a diagonal-transect method (Southwood, 1978). After 4 years of the same GMS treatments, groundcover species mixtures and relative dominance in each plot were relatively stable by Oct. 1989, and negligible growth of surface vegetation occurred during the dormant season (mid-October to mid-April in upstate New York). Be-

cause the observed GMS trends in dormant-season groundcover vegetation were consistent from 1989 to 1992, we assumed that the values we had determined for groundcover biomass and surface coverage in Oct. 1989 were representative of subsequent dormant season surface vegetation, and could be correlated with our early winter vole population counts in later years as well.

A repeated-measures analysis of variance (ANOVA) model was used to test GMS effects on vole populations and tree damage during the 3 years of intensive monitoring. To compare vole activity and populations among GMSs within sampling times, feeding activity and trap counts during consecutive days were used as separate estimates of total populations at each sampling interval (Caughley, 1977). Vole population counts in each GMS plot were transformed to natural logarithms of cumulative vole counts (+1 to allow for zero counts), and compared using analysis of variance and Protected Least Significant Differences (LSDs). Vole feeding activity was indexed from one to five, where 1 = 0% to 20% of apple slices consumed, and 5 = 80% to 100% consumed in each plot (Byers, 1975). We then used linear regression models to test

the relationship between groundcover biomass or percentage vegetation coverage of plot surfaces and the observed vole populations or girdling damage to trees (Steele and Torrie, 1980).

Results and Discussion

ANOVA for data pooled over 3 years of sampling indicated that GMS treatments, years, sampling times within years, and interactions between GMS and sampling times all were significant sources of variation ($P = 0.001$). Treatment means and trends were therefore presented and analyzed for each 3-day vole census (Fig. 1 A and B). There were substantial differences in vole populations among different GMSs at all sampling times except Apr. 1991. The November trapping and subsequent winter mortality caused large fluctuations in meadow vole populations each year. Although meadow and pine voles are known to coexist in some New York orchards, we did not capture or observe any pine voles in this study, because the primary range for pine voles is farther south and the silt-loam soil at our site was not sufficiently well drained for the deeper burrowing and nesting habits of

Fig. 1. Comparison of meadow vole feeding activity and population counts in eight groundcover management systems over a 3-year period using two monitoring methods: (A) Byers' slice index (proportion of bait consumed) and (B) trap counts (number of voles per trap per night). Each value is the mean of six treatment replications; vertical bars represent LSDs ($P = 0.05$) for each census time.

pine voles (Tobin and Richmond, 1993). Population estimates based on our modification of Byers' (1975) feeding activity indices were similar to corresponding trap counts (Fig. 1A vs. 1B), confirming Byers' index as a reliable nondestructive method for estimating vole population densities and potential damage in apple orchards.

Vole feeding activity and trap counts were higher in CNVCH and STMCH than in other GMSs on most occasions, higher in GRSOD than in herbicide or tilled treatments in Oct. and Nov. 1990 and July 1991, and higher in MWSOD and GRSOD than in herbicide or tilled treatments in Oct. 1990 and Nov. 1992 (Fig. 1A and B). Populations in GRSOD, STMCH, or CNVCH plots were usually high in midsummer or fall, and low in spring. Herbicide type (preemergence vs. postemergence) and strip width (1.5- vs. 2.5-m-wide treated strips) did not appear to affect vole densities. In herbicide and tilled GMS treatments, voles were usually scarce or nondetectable and few surface foraging runs were evident after winter snow melt in these GMSs, even when adjacent to CNVCH or STMCH plots with high vole populations. This confinement of meadow vole activity and feeding within rather narrow plots of favorable habitat confirms their strong aversion to crossing open ground and limited dispersal within orchards even when snow provides protective cover for their foraging or migration (Byers, 1984; Tobin and Richmond, 1993).

Despite previous reports that crownvetch was toxic to meadow voles in caged feeding studies (Lewis et al., 1983; Shenck et al., 1974), we observed foraging on crownvetch leaves (but not stems) by voles in this GMS. The densely matted crownvetch also supported substantial vole populations, and its long procumbent stems provided bridges for voles to climb over and inside the mesh guards, gaining access to feed on tree trunks. Previous results from caged feeding studies may not be applicable under orchard conditions, where mixed diet choices and habitat factors influence vole behavior and survival (Byers, 1984). The hay-straw mulch itself did not appear to be utilized as a food source for meadow voles, but they burrowed and nested readily in this material. Hunting of voles by foxes (*Vulpes fulva* Demarest), kestrels (*Falco sparverius* L.), and redtailed hawks (*Buteo jamaicensis* Gmelin) was observed on many occasions in our study, especially in the GMS treatments with high vole densities (Fitzgerald, 1977; Howard et al., 1982). Despite these natural predators, voles still significantly damaged trees in GMSs that provided favorable habitat.

Groundcover shoot and leaf biomass was a weak but significant predictor of vole populations in 1990 and 1992. Linear regressions of log-transformed November vole counts (zero counts excluded) on groundcover biomass ($\text{g}\cdot\text{m}^{-2}$) fit the data with model P values of 0.07 and 0.008, r^2 values of 0.14 and 0.27, and standardized slope coefficients of 0.37 and 0.52, for 1990 and 1992, respectively. The irregular and nonuniform distribution of voles among GMSs at this orchard was evident in

Fig. 2. Cumulative percentage of trees with meadow vole damage to lower trunks after 6 years of treatments with eight groundcover management systems. Vertical bars on each column represent SEs of six replicates per treatment mean.

Fig. 3. Cumulative mean percentage of trunk circumference girdled by meadow vole feeding from 1990 to 1992, with no protective treatments (Control), plastic mesh trunkguards (Meshguard), or trunk applications of Thiram in latex paint. Vertical bars above columns are SEs of mean for six treatment replications.

our data. At each census, no voles were observed in some plots with substantial groundcover biomass. In fact, in 1991 there was no significant relationship between groundcover biomass and vole counts ($P = 0.55$ for linear regression model). We attributed these observations to risk-averse behavior (hesitance to cross bare ground or close mowed driveways between plots) and to predator limitation of meadow vole dispersal (Getz, 1961; Godfrey, 1987; Sullivan and Hogue, 1987). Even when suitable vole habitat was available <4 m from high population concentrations in adjacent GMS plots, they often did not migrate or forage from one tree row to another. These observations demonstrate the importance of orchard habitat management for integrated meadow vole control.

Dormant-season groundcover biomass in STMCH plots consisted mostly of quackgrass

(84%, *Agropyron repens* L.), and curly and broadleaf docks (9%, *Rumex crispus* L. and *R. obtusifolia* L.); in CNVCH plots it was predominantly crownvetch (77%) and dandelion (11%, *Taraxacum officinale* L.). However, the percentage of plot surface covered by individual or associated groundcover species was not a significant predictor of vole populations (data not shown). As described in a previous report (Merwin et al., 1994), a persistent layer of moss <1 cm thick developed in plots of the glyphosate herbicide GMSs. This moss provided an average of $\approx 70\%$ of soil surface coverage during dormant seasons, but constituted negligible groundcover biomass and was evidently unsuitable habitat for meadow voles.

Cumulative vole damage to trees from 1987 to 1993 was greater in the CNVCH and STMCH than in all other treatments, and caused serious losses of trees and yield in those two

GMSs, despite the suppression of voles by rodenticide baiting from 1987 to 1989, and attempted vole trapouts each November from 1990 to 1992 (Fig. 2). Cumulative tree mortality from 1989 to 1992 averaged 38% in STMCH plots and 14% in CNVCH, but substantially less in the other GMSs. We could not attribute tree mortality in STMCH entirely to meadow vole depredation, because 35% of the trees in this GMS also were also affected by *Phytophthora* root rot during our study (Merwin et al., 1992).

There was a strong interaction ($P = 0.001$) between GMSs and the efficacy of trunk protective treatments (Fig. 3). The incidence of vole damage to trees from 1990 to 1993 in thiram-treated, plastic-mesh-guarded, and unprotected control treatments revealed that mesh guards were more effective than thiram, but thiram was better than no trunk protection for reducing vole damage. In combination with destructive trapping each November, mesh trunkguards provided adequate protection for trees even in STMCH and CNVCH treatments; however, almost 40% of thiram-treated trees and 90% of the unprotected trees were damaged in STMCH plots with high vole densities. Painting lower trunks with thiram appeared to provide adequate protection only when meadow vole populations were low and groundcover habitat was unfavorable for this pest.

After 5 years of observations we conclude that multiple pest management tactics can provide optimal control of meadow vole damage in apple orchards. When groundcover management systems offer favorable habitat for meadow vole nesting and foraging, rodenticide applications may not provide adequate control. However, regular mowing of turfgrass row middles appeared to suppress vole dispersal and migration between suitable tree-row GMSs within the orchard. Meadow-vole feeding activity on apples beneath trees provided a reliable indication of vole population density and potential damage to trees. Three days of lethal trapping each November sub-

stantially reduced overwintering vole populations in the orchard. When lethal trapping was combined with mesh-guard trunk protection and close mowing of the drive lanes in and around the orchard, negligible meadow-vole damage occurred to trees during three consecutive dormant seasons without applications of toxic rodenticides.

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