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ABSTRACT

Pine voles (Microtus pinetorum LeConte) were maintained as known populations (0, 269, 538 and 1075/ha) in wire mesh-enclosed blocks of 'McIntosh'/M26 apple trees (Malus domestica Borkh.) for 2 years. There was little measurable effect of the voles on growth and production the 1st year, but during the 2nd year the highest population was associated with the death of one tree; severe reductions in growth, yield, and fruit size; a 78% reduction in crown bark weight, 56% loss of fibrous roots, and a dramatic reduction in the value of the crop. Although the low and the medium populations showed little effect on yield, there was a reduction in vegetative growth in the medium population plot that was associated with extensive root girdling, fibrous root reduction and substantial bark loss by the end of the 2nd year.

INTRODUCTION

Pine vole damage to apple trees continues as a major problem in many central and eastern states. The loss of phloem and cambium from the lower trunk and large roots (Horsfall 1953, Byers 1976) frequently results in the death of the tree. Past assessments of damage as well as measures of economic loss have been based largely on such whole tree losses (Byers 1974, Sutton et al. 1981). While this approach provides a useful first approximation of damage, we now know that substantial losses in growth and yield of damaged but surviving trees also occurs (Pearson and Forshey 1978, Forshey et al. 1984).

The effects of known population levels on known-age trees with a growth history of no previous damage has allowed a more refined assessment of tree growth and vigor, fruit production and whole tree survival (Forshey et al. 1983). Coupled with this above-ground assessment of growth and productivity is a database that contains details of crown and root effects caused by the same known populations of voles. The purpose of this paper is to evaluate these data in light of previous analyses and thereby provide a comprehensive picture of pine vole damage effects for both the aerial and subterranean portions of an apple tree.

METHODS

Details concerning study site and experimental design are presented in previous papers (Richmond and Miller 1982, Forshey et al. 1984), however, a brief recounting is useful here. In autumn of 1981, thirty-two 10-year-old 'McIntosh'/M26 apple trees in a 2.4 x 2.4 x 4.8 m double offset-row planting were selected for experimentation. The trees were of uniform size, in good production, and with no previous vole damage. Four unreplicated blocks of 8 trees each were identified, fenced and stocked either with a low, medium, or high

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population. The 4th block served as a control. While replication would have been desirable from the standpoint of statistical analysis, this particular experimental design was the most practical under the circumstances. The volume of work limited the number of trees per treatment plot and smaller plots would have placed unnatural restrictions on the movement and habitat use by the voles. A trench was dug completely around each block, and a 1.27 x 1.27 cm wire mesh fence was installed to a depth of about 45 cm and extended to a height of about 45 cm above ground. Aluminum tape 5 cm wide was placed around the top of the enclosure to prevent escape by climbing.

In order to maintain known vole densities, yet ensure that vole social organization closely approximated natural conditions and that the plots provided habitat suitable for reproduction, the enclosures were stocked as follows: low density: 1 adult male and 1 adult sterile female (oviduct ligation); medium density: 2 adult males and 2 adult sterile females; high density: 4 adult males and 4 adult intact females. These densities were the equivalent of 269, 538, and 1075 voles/ha. The 4th enclosure (0 voles) served as the control. The populations were monitored at least monthly by live trapping, and additional voles were released as necessary to maintain the desired numbers. Although some breeding was evident in the high density enclosure, the number of adult voles never exceeded eight. Populations in all three enclosures adapted quickly and established burrow systems typical of those found elsewhere. Over the two-year study, only 7 replacement voles were used.

After two years exposure of the trees to the voles, all of the trees were dug from the plots. The crown, and virtually all of the root mass were saved for a variety of measurements including the extent of vole damage.

RESULTS

In early spring of 1982, there was visible girdling of the crowns of some trees. Most, but not all of this girdling occurred in the enclosure with the highest population (1075/ha). During the 1982 growing season, there were no visible differences between the control and the plots with the 2 lower populations, however, the plot with the highest population was noticeably reduced in vigor. This reduction was reflected in depressed leaf levels of N and K, and in a 37.5% reduction in terminal shoot growth (Forshey et al. 1984). In spite of reduced vigor, there was no effect on yield or fruit size (Table 1).

Table 1. Effects of 3 pine vole population levels on 1982 and 1983 yield and fruit size of 'McIntosh' apples.[a]

	No. of Pine Voles/ha			
Year	0	269	538	1075
	Yield (boxes/ha)[b]			
1982				
Mean	2389	2367	2557	1917
SD	405	356	511	383
1983				
Mean	1055	924	986	363
SD	227	183	193	146
	Mean fruit wt (g)			
1982				
Mean	101.9	102.9	110.4	112.7
SD	8.0	8.8	8.2	9.2
1983				
Mean	105.7	98.9	90.7	53.7
SD	8.3	6.4	6.6	6.6

[a] Table from Forshey et al. 1984.
[b] One box = 18 kg.

The crop in 1983 was less than one-half that of 1982. This was due to a combination of factors that were in large part unrelated to vole activity: 1) the 1982 crop was very heavy and this reduced the potential for 1983, 2) the spring of 1983 was wet and cold with frequent frosts (National Climatic Data Center 1983) thus limiting fruit set, and 3) severe drought developed during the latter half of the growing season adversely affecting fruit size.

There was no measurable effect of the low or medium populations on yield or fruit weight in 1983, but the highest population reduced yield by 65.5% (Table 1). To compound this loss, 57.5% of the apples were undersize (Table 2). The absence of an effect on fruit yield and size in the low and medium populations is surprising in view of the data in Tables 3 and 4 showing such a marked reduction in crown bark and fibrous roots in all three vole plots. The most plausible explanation for this is that the cumulative damage done over the two years was not extensive enough to show a reduction in fruit yield and size by the second season. Another possibility is that the bulk of the damage in the low and medium density plots occurred for unknown reasons during the second year and these effects were not yet detectable in the second year crop. Unfortunately, we could not separate the root damage into year classes and were able to identify only recent damage as opposed to past damage.

Based on fruit size distribution (Table 2), fruit color data, and prices prevailing at harvest, the average selling price/box was $7.81. for the control and $3.47 for the highest population (Table 5). This reduction in unit value in combination with the reduction in yield, amounts to a difference in gross receipts of $6779/ha.

The total length of the root configurations varied somewhat between trees but as expected was not different between plots (Table 6). The number of sites along the roots that had been gnawed by voles was rather high in all three of the plots

Table 2. Effect of three pine vole population levels on the distribution of grade and size of 'McIntosh' apples.

	No. Pine Voles/ha			
	0	269	538	1075
Grade and Size	Harvest %	Harvest %	Harvest %	Harvest %
Undersize[a]	3.1	5.7	7.5	57.5
U.S. No. 1				
Poly bags[b]	9.5	17.2	20.1	15.1
Cell packs[c]	21.4	13.6	22.1	17.0
U.S. Fancy				
Poly bags[b]	27.6	28.8	18.2	4.0
Cell packs[c]	38.4	43.7	32.1	5.4

[a] Less than 57 mm in diameter.
[b] Fifty-seven-63 mm in diameter.
[c] Greater than 63 mm in diameter.

Table 3. Effect of three vole population levels on fresh weight of the crowns, total root structure, and dry weight of crown bark on 'McIntosh' apple trees.

	No. Trees		No. Pine Voles/ha 0	269	538	1075
Crown weight (Kg)						
	7-8	$\bar{X}$	6.44	5.42	5.40	4.67
		SD	1.06	0.69	1.26	1.98
Percent reduction from control			0	16	16	27
Roots (Kg)	7-8	$\bar{X}$	4.45	3.55	3.30	2.86
		SD	0.85	1.50	0.67	1.51
Percent reduction from control			0	20	26	36
Crown Bark (gm dry wt/10 cm^2 of surface area)	7-8	$\bar{X}$	21.2	15.2	12.3	4.7
		SD	4.5	4.7	4.8	2.4
Percent reduction from control			0	28	42	78

Table 4. Effect of three vole population levels on weight and relative abundance of fibrous roots of 'McIntosh' apple trees.

	No. Trees		No. Pine Voles/ha 0	269	538	1075
Fibrous roots gms. dry wt.	7-8	$\bar{X}$	195.7	112.1	122.0	85.2
		SD	73.1	65.3	47.7	46.5
Percent reduction from control			0	43	38	56
Fibrous roots gms. dry wt/ 100 cm root lgth.	7-8	$\bar{X}$	9.9	5.4	6.8	4.4
		SD	3.5	1.5	2.5	1.1
Percent reduction from control			0	45	31	56

Table 5. Effect of three pine vole population levels on selling price and subsequent market value of 'McIntosh' apples.

		No. Pine Voles/ha			
		0	269	538	1075
Grade and Size	Price per box[d/]	Crop value per box	Crop value per box	Crop value per box	Crop value per box
Undersize[a/]	$ 1.80	$ 0.06	$ 0.10	$ 0.14	$ 1.04
U.S. No. 1					
Poly bags[b/]	1.80	0.17	0.31	0.36	0.27
Cell packs[c/]	7.00	1.50	0.95	1.55	1.19
U.S. Fancy					
Poly bags[b/]	6.75	1.86	1.94	1.23	0.27
Cell packs[c/]	11.00	4.22	3.82	3.53	0.70
Avg. price/box		$ 7.81	$ 7.12	$ 6.81	$ 3.47

a/ Less than 57 mm in diameter.
b/ Fifty-seven-63 mm in diameter.
c/ Greater than 63 mm in diameter.
d/ Prevailing prices at the time of harvest.

Table 6. Effect of three vole population levels on the frequency of damage to the root structure.

	No. Trees		No. Pine Voles/ha			
			0	269	538	1075
Total Root Length (cm)	7-8	$\overline{X}$	2314.5	2043.0	1835.4	2089.1
		SD	460.4	660.2	460.8	1389.0
No. Vole Damaged Areas/ 100 cm root	7-8	$\overline{X}$	0	1.9	1.1	2.3
		SD	0	0.9	0.3	1.9

stocked with voles but was highest (2.3 injuries/100 cm) in the high vole density plot. The medium and low vole plots sustained fewer injuries but on average revealed from 1.1 to 1.9 gnawing injuries per 100 cm of root. The fact that the medium vole density plot sustained fewer injuries than the low density plot merely reflects the variable nature and pattern of vole damage to the root structure. While the correlation statistic ($r = -0.394$) is weak for vole density and number of damaged sites/100 cm, r values are high for crown bark weight reduction ($r=0.86$), and root bark dry weight ($r=0.79$) relative to vole density. As expected, the correlation between crown bark weight and root bark weight loss is likewise high ($r=0.73$). Part of the explanation for this lies in the distribution pattern of the damage within the root mass of an individual tree and the distribution of damage among the trees in the plot. In short, extensive gnawing activity at 1 or 2 trees will result in a reduced number of injury sites but will cause an equivalent degree of bark removal in the plot. Each injury site simply becomes larger. Other variables that operate to determine the pattern of damage within a plot include both the amount and distribution of other foods, the suitability of soils for extending the burrow system and thus the foraging range, and the site within the plot that is chosen for nesting location and center of vole activity.

Table 7 shows the percent reduction in root bark dry weight (gms/cm^2) in the three vole plots versus the control. The high density plot shows a remarkable 66% reduction in root bark after two years of vole exposure as previously described. These trees were indeed doomed and at least one was already dead when dug. The others in this plot may have

Table 7. Effects of three vole population levels on the amount of root bark remaining on the 'McIntosh' apple trees.

	No. Trees		No. Pine Voles/ha 0	269	538	1075
Sample Bark[a] dry wt. (gm)	7-8	$\bar{X}$	152.4	180.2	144.4	79.8
		SD	62.7	77.5	45.3	36.6
Sample Bark[b] surface area (cm^2)	7-8	$\bar{X}$	1259.0	2159.8	1640.6	1748.8
		SD	293.7	1123.5	649.9	700.0
Bark dry wt./ unit area ($gms./cm^2$)	7-8	$\bar{X}$	.135	.090	.093	.045
		SD	.027	.026	.034	.005
Percent reduction in $gms./cm^2$ from control			0	33	31	66

[a] A grab sample of root segments approximating 30% of the total root mass and equivalent to 6.5 to 7.5 m in length.

[b] Determined from the length and diameter of the root segments in the grab sample.

progressed to leaf out in the third year but no more than one or two would have survived through the third summer. Root samples from the medium and low density plots showed a 31% and 33% reduction in bark, respectively (Table 7). Once again the low density plot revealed as much damage as the medium density plot. We can only speculate that voles in the low density plot either preferred apple tree roots to other vegetation in the plot or that because of the distribution of other food and cover, greater utilization was made of apple tree roots.

Table 8 indicates a pattern of root girdling that is in concert with other measures of root damage reported here. A nearly equivalent amount of damage was seen in the low and medium vole plots which showed major damage (26 to 100% girdling) to 12 and 15% of the crown roots, respectively. The high vole plot had major damage to 35% of its crown roots with 21% showing from 75 to 100% complete girdling. The data suggest a skewed pattern of damage to crown roots with the bulk of the observations occurring in the highest and lowest damage categories with fewer observations in the middle categories. This may reflect the tendency of voles to continue feeding at a particular site on a root until girdling of that root is nearly complete. If the remaining bark tissue at an injury site were detected by voles to carry an increased load of nutrients while simultaneously generating new bark growth at the site, then persistent gnawing at this location could be expected and would result in a higher frequency of complete girdling. The increased frequency of damage in the lowest category (1-25%) is likely due to the fact that while numerous minor damage sites occur throughout the root system, all those associated with crown roots are easily detected.

DISCUSSION

A complicating feature of assessing vole damage to the roots and crown of a tree is due to the shape and function of the roots coupled with the variable pattern of gnawing by the voles. The complete

Table 8. Frequency distribution of the percent of crown roots girdled by voles.

Vole Density	No. Trees	No. Crown roots[a]	Frequency and Percent of Crown Root Girdling 0	1-25	26-50	51-75	76-100
Control	8	43	43	0	0	0	0
Low vole (269/ha)	8	41	23	13	2	1	2
Med. vole (538/ha)	7	40	25	9	2	0	4
High vole (1075/ha)	7	34	14	8	4	1	7
TOTAL	30	158	105	30	8	2	13

[a] Major roots emanating directly from the crown.

girdling of a major root may remove only a small amount of bark and be noted as a single injury point but will kill that root distal to the point of injury. Conversely, a similar root may show several injury points and experience removal of a large amount of bark on one side. In this instance, the recording of injury and bark removal is high yet the root survives and continues to function.

Within the limits of this unreplicated experimental procedure, the descriptive statistics coupled with simple observation indicate that apple trees of the age and stock used here cannot withstand the girdling and bark removal effected by the high vole population (1075/ha) for two consecutive years. The capacity for growth and production was virtually eliminated from all trees in this plot and survival of the trees through a third year was highly unlikely. As stated previously, older trees, wider spacing, different cultivars or more vigorous rootstocks could alter the survival time, however, major damage would still be predictable and apple production likely would be no longer economically feasible (Forshey et al. 1984).

Although the medium vole population (538 voles/ha) did not reduce yield by the end of the second year, vegetative growth was reduced in the second year and a drop in apple production could be safely predicted for year three and beyond. The number of damaged areas inflicted by 4 voles was about half of that seen in the plot with 8 voles. There was a similar pattern with regard to loss of crown bark, root bark and fibrous roots from this plot. It is notable that 15 of the 40 crown roots (Table 8) showed some damage and 4 of these 15 were completely girdled. Continued survival of all 7 trees in the plot could be expected through year 3; however, production and survival beyond that time would not be likely for all trees if the rate and pattern of damage continued as in the first 2 years.

The low density (269 voles/ha) plot responded much like the medium density plot with regard to fruit production and vegetative growth (Table 1) for unexplained reasons, however, a substantial amount of minor damage to the root systems throughout the plot (Table 6) and a high degree of removal of fibrous roots (Table 4) suggest a potential reduction in health and productivity of these trees in future years. Of course, if the pair of voles in this plot had elected to live and feed at only 1 or 2 of the trees in the plot, then damage to a particular tree would have been severe and the tree might have been killed.

The inclination to extrapolate downward to 1 vole per plot or some other reduced number of voles per unit area in order to possibly arrive at a density of voles that is tolerable by the trees is tempting. However, pine voles are not normally distributed in groups smaller than 2 per unit area. Therefore, the data presented here are realistic in terms of damage to those trees within reach (normally the home range) of the voles. A significant point here is that vole density within a large orchard or other tree crop is not as critical to predicting the well-being of the trees as is the density around a particular tree or small group of trees. It is also notable that while the density of voles in the three plots may seem high when expressed on a per hectare basis, family units of voles in excess of 10 voles per tree are not infrequently found and groups of 3 to 7 animals are the rule in most naturally occurring family groups.

CONCLUSIONS

1. Small groups of voles, even pairs, can inflict substantial damage to the roots of apple trees under the

conditions of confinement to a particular group of trees.

2. A reduction in tree growth and productivity was observed in the high and medium vole density plots after two years exposure to voles and damage to the roots was notable at all three levels of vole density.
3. The nature of vole social organization and their limited range puts any single tree at risk of death if young in age, and loss in productivity if older. Voles inflict damage not as a consequence of their population level but as a social unit (family) with a small foraging area.
4. Details of root damage assessment become only academic if girdling of the crown occurs. But, in the absence of severe crown damage, considerable reduction in growth, vigor, and productivity can be caused by crown root damage and loss of fibrous root biomass.

LITERATURE CITED

BYERS, R.E. 1974. Pine mouse control in apple orchards. The Mountaineer Grow., March. p. 3-13.

BYERS, R.E. 1976. Review of pine vole control methods. Proc. Va. State Hort. Soc. 64:20-32.

FORSHEY, C.G., R.W. WEIRES, B.H. STANLEY and R.C. SEEM. 1983. Dry weight partitioning of 'McIntosh' apple trees. J. Amer. Soc. Hort. Sci. 108(1):149-154.

FORSHEY, C.G., P.N. MILLER and M.E. RICHMOND. 1984. Effects of differential pine vole populations on growth and yield of 'McIntosh' apple trees. HortScience 19(6):820-822.

HORSFALL, F., JR. 1953. Mouse control in Virginia orchards. Va. Agr. Expt. Sta. Bul. 456:1-26.

NATIONAL CLIMATIC DATA CENTER. 1983. Climatological data, New York, NOAA. Asheville, NC.

PEARSON, K. and C.G. FORSHEY. 1978. Effects of pine vole damage on tree vigor and fruit yield in New York apple orchards. Hort. Sci. 13:56-57.

RICHMOND, M.E. and P.N. MILLER. 1982. Effects of known densities of pine voles on apple trees. Proc. Sixth Eastern Pine and Meadow Vole Symp., Harper's Ferry, WV. 6:39-42.

SUTTON, T.B., D.W. HAYNE, W.T. SULLIVAN, JR., J.F. NARDACCI and D.E. KLIMSTRA. 1981. Causes of apple tree death in Henderson County, North Carolina. Plant. Dis. pt. 65:330-332.