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The effectiveness of orchard management, as in any agricultural system, is judged on the total quantity and quality of the produce and on the financial return per unit of investment. Decisions affecting orchard management are based ultimately on economic factors.

This economic criterion should, therefore, be applied to all orchard pest management decisions--including control of the pine vole (Pitymys pinetorum). The purpose of this paper is to describe an approach we are taking to identify factors useful in estimating the economic threshold which can form the basis for cost-effective management of the pine vole and the meadow vole (Microtus pennsylvanicus) in apple orchards.

Dyer and Ward (1977) and Dolbeer (1981) state that the decisions in management of pest species should be based on economics. Key factors in economics-based pest control include: estimation of losses caused by short- and long-term damage as a function of pest populations; cost of measures to control the pest within defined population levels; and the opportunity costs of the control measures. When these factors are known the pest control specialist, the orchard manager, and the researcher can make wise judgements on actions to take against the depredating species.

Rodent damage control in apple orchards has evolved largely through use of standard orchard practices. Studies are not available to quantify the levels of damage necessary to determine what control measures are economically justified, or even to identify the range of damage that would establish cost-effectiveness.

There are several reasons for this lack of knowledge. The damage done to apple trees is not easily observed, described, or measured. There is probably not a simple linear relationship between bark removal and economic damage. In addition to these difficulties and because the tree is a perennial, there is cummulative damage as well as recuperative and compensatory processes. In numerous situations, compensatory growth has been suggested and actually demonstrated (Dyer 1973, 1975, 1976, Dyer and Bokhari 1976, Harris 1974, Hutchinson 1971, Pearson 1965, Vickery 1972, Westlake 1963, and Woronecki et al. 1976).

To date, only a few attempts have been made to address the economics of pine vole or meadow vole damage in orchards. Pearson (1976, 1977) and Pearson and Forshey (1978) examined the relationship between the presence of voles and tree damage expressed as a reduction in crop value. A few authors have made some theoretical and speculative estimates of damage (Kennicott 1957, Hamilton 1938, Garlough and Spencer 1944, Biser 1967, and Byers 1974). Recently Sullivan et al. (1980) have reported some standard survey work

examining the magnitude and causes of tree mortality. This gives some concept of economic damage, but cannot be used to isolate even the benefits of current rodent control techniques. Ferguson (1980) and Luttner (1978) have also produced some very broad economic generalizations by extrapolating form rodenticide use figures. These, however, are only measures of standard acceptable orchard practice, and cannot form the basis for vole management in orchards.

A simple description of damage to an apple tree root system is not available. The depth to which damage extends is available only as antedotal information (Benton 1952). Even the simplest understanding of rodent damage, and the response of the tree to such damage, is not currently available. No studies are available which relate the death of trees to the removal of root tissue. There is no information to suggest at what level tissue removal may begin to impair growth, or at what level growth impairment may begin to reduce crop yields and the productive life-span of the tree.

Such information is essential to wise management, and might suggest that 100% control, an industry standard, may be neither necessary nor desirable. We have proposed three studies that should help define the economic threshold level of pine voles and improve our understanding of and recommendations for the moderately damaged tree. These types of studies should also aid in identifying methods useful for making careful damage assessments that are now lacking in pine vole control literature.

METHODS

The first study will address the unsubstantiated hypothesis that vole density is a most important factor in root damage. This study will involve enclosing known vole populations within 0.008 ha fenced plots which contain eight apple trees. The trees are McIntosh on M-26 rootstock and are in their ninth leaf. Vole populations equivalent to 247, 494, and 740+ (family group) voles per ha will be placed within enclosures. Harvest records, shoot growth and leaf analyses, which have been collected during previous research projects, will continue to be done for all trees in each enclosure. When shoot growth, leaf nutrient analysis, and tree specific crop loads are correlated with vole densities, this study should yield information directly related to the economic threshold. If root systems within the enclosed plots are excavated, an even fuller understanding of vole damage on trees should be gained.

To study the long-term, cummulative effects of pine vole damage, a second study will examine the root systems of damaged mature trees. By selecting trees of poor, moderate, and high vigor, a correlation between levels of root damage and the various degrees of tree vigor may be established. A few trees will be removed by excavating all root material greater than 1 cm in diameter. Root material will be sectioned into approximately straight cylindrical segments. The distance between the root crown and each segment will be recorded, and the surface area will be estimated ($\pi \cdot \text{diameter} \cdot \text{height}$). The portion of the surface area which has been damaged will be estimated

using a helical line-transect to sample damaged and undamaged bark on each root segment. The amount of damaged tissue, recorded within 0.5-m zones of the root crown, will be correlated against shoot growth, leaf nutrient analysis, and tree specific harvest records. It is expected that most root systems would not be totally excavated but will be sampled by cutting a 2-m deep trench across the diameter of the dripline (through or immediately adjacent to the tree base). A 15-cm segment of each root exposed will be removed and handled as detailed above. The location (vertical and horizontal) of each exposed segment will also be noted.

The third and later study would examine the possibilities that a damage level accumulated over years of exposure would cause a significantly different reduction in yield than does a one-time exposure to the same damage level. This question can be approached by excavating the root crown and proximal portion of all roots attached to the crown. The desired percentage of damage will be obtained by measuring the total circumference of the exposed roots and the girdling of that portion of the total circumference which is prescribed by the damage category. The levels of damage chosen for each category will correspond to the levels of root girdling observed in the second study.

CONCLUSIONS

The three studies will improve our knowledge of the dynamic relationship between voles, damage, and actual economic loss. The expected insights are numerous and may form the basis for new control techniques. It is disconcerting not to have a good, even simple, understanding of the actual damage (root tissue removal) done by pine voles. A systematic examination of this first order damage is important because it has never been done, and in its absence we may be missing important understandings relating to the functional mechanisms and more importantly the control of pine vole damage.

Through a simple comparison of results from our three studies, several additional observations should be possible. By comparing results from the second and third studies, the importance of damage location (e.g., root hair versus root girdling) and secondary damage (e.g., fungus) should be understood. Comparisons from these studies should also identify damage levels of no or only temporary significance. The results from the first study will be the most direct attempt to determine an actual economic threshold population available to date. This should also provide additional understanding of the relative importance of root hair feeding versus root girdling.

Dolbeer (1981) urged animal damage control researchers to spend half their effort in the study of the economic implications of damage and damage control. Although studies proposed here do not reach this goal, they will begin to improve our understanding of the economics of pine vole damage particularly for the soil types, and age classes of trees in these studies. Only through a fuller understanding of the relationship between voles, trees, crop loss and

control efficacy, can we refine our ability to consistently make the most appropriate and economically-sound management recommendations for the control of pine vole damage in commerical apple orchards.

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