THE EFFECT OF ACORN INSECTS ON THE ESTABLISHMENT AND VIGOR OF NORTHERN RED OAK SEEDLINGS IN NORTH-CENTRAL WEST VIRGINIA

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Abstract: During a 2-year investigation into the effect of small mammals on northern red oak (*Quercus rubra*) acorn survival and germination, widespread germination failure and lack of seedling vigor was apparent in control quadrats on one of two watersheds under study. Insects were present in and on the failed acorns but it was unknown whether they were primary invaders or merely scavengers. The purpose of the present study was to determine: 1) the proportion of acorn failure that could have been attributed to insect infestation, and 2) the effect of cotyledon damage due to insects on the vigor of northern red oak seedlings. Northern red oak acorns were collected from good and excellent sites on the two watersheds in October 1993. All acorns located under the crowns of 40 study trees were collected and float-tested for viability. Samples of 18 apparently sound acorns were placed in mammal exclusion cages under each of the study trees; nine acorns were buried and nine were placed on the soil surface. In late spring of 1994, any failed acorns and seedlings with cotyledons attached were dissected. Insect presence or damage, percent cotyledon damage, and overall vigor were recorded. Anaylses of variance (ANOVAs) were used to compare: 1) mean seedling vigor by watershed, year, and treatment, 2) insect infestation rates on the two sites and between treatments in 1994, and 3) the effect of cotyledon damage on seedling vigor in 1994. Important results include the identification of three insect pests in germinating northern red oak acorns in north-central West Virginia and the finding that insect infestation may decrease vigor but does not necessarily preclude germination or seedling establishment.

INTRODUCTION

During the course of a 2-year study to determine the effects of small mammals on the survival of northern red oak acorns (*Quercus rubra*), widespread germination failure and lack of seedling vigor were noted on control plots that were protected from rodent damage with screening (Gribko and Hix 1993). Surface-sown acorns fared poorly in both years on one of two watersheds under study. Insects were present in and on the failed acorns but no detailed investigation of the cause of failure was made. Since insect damage was suspected to play a role in the lack of seedling success, a study was initiated in the fall of 1993 to investigate the impact of insects on germinating northern red oak acorns.

In most studies of acorn insects, *Curculio* weevils (Coleoptera: Curculionidae) are found responsible for much of the damage to acorn crops (Brezner 1960, Tryon and Carvell 1962a and 1962b, Marquis *et al.* 1976, Gibson 1982, Weckerly *et al.* 1989, Oak 1992). Infestations of an acorn moth, *Melissopus latiferreanus* Walsingham (Lepidoptera: Oleuthreutidae), and gall-forming wasps of the genus *Callirhytis* (Hymenoptera: Cynipidae) may also be severe in certain years (Gibson 1982, Oak 1992). All of these insects have been established as primary pests of northern red oak acorns (Gibson 1982). As such, they are capable of breeding in otherwise sound acorns as they develop on the tree. In the small mammal study initiated in 1990, an intense effort was made to eliminate acorns that were infested with primary pests. Therefore, if insects did contribute to the observed seedling failure, it is highly probable that species other than these were responsible.

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Other insects, although present in collections of northern red oak acorns, have often been disregarded due to their low numbers or to the perception that they act primarily as scavengers of the frass and detritus left in acorns vacated by primary pests. Unlike primary invaders, these insects cannot breach the acorn shell and are limited to damaged, previously infested, or germinating acorns for oviposition sites. The most important insects in this group are: 1) weevils of the genus *Conotrachelus* (Coleoptera: Curculionidae) 2) an acorn moth, *Valentinia glandulella* Riley (Lepidoptera: Blastobasidae), and 3) a nitidulid sap beetle, *Stelidota octomaculata* Say (Coleoptera: Nitidulidae). Three species of *Conotrachelus* weevils have been observed breeding in acorns in the United States: *C. posticatus* Boheman, *C. naso* Leconte, and *C. carinifer* Casey. All three are capable of breeding in captivity in northern red oak acorns. (Gibson 1964). However, *C. carinifer* is primarily a coastal species more commonly found infesting bottomland oaks. It has appeared in collections of northern red, black (*Quercus velutina)*, and scarlet oak (*Quercus coccinea*) from Georgia (Gibson 1964), but Brooks (1910) makes no mention of this species in West Virginia and it will not be discussed further here. Of the remaining two species, *C. posticatus* appears to be the most serious pest of northern red oak (Winston 1956, Gibson 1964, Galford *et al.* 1988).

Gibson (1964) reports that adults of *C. posticatus* appear from June to August and begin mating and ovipositing within days of appearing. Rather than ovipositing in acorns as they mature on the tree, *Conotrachelus* weevils wait until they fall to the ground and then deposit eggs through cracks or other openings in the shell. The eggs hatch within days of being laid and the larvae pass through 5 instars before emerging from the acorn in 2-4 weeks. The larvae then burrow down into the soil and construct pupation cells by twisting their bodies until a sealed chamber has formed. It has been suggested that under natural conditions *C. posticatus* will pass the first winter in the larval stage and will not emerge as adults until late spring or early summer of the following year (Gibson 1964). The weevils will then pass their second winter in the adult form. However, both Brezner (1960) and Gibson (1964) report that under laboratory conditions *C. posticatus* will pupate immediately and overwinter as adults.

Conotrachelus weevils were historically considered to be pests of oaks in only the white oak group. However, this conclusion was reached based only on observations made in autumn when the weevils were found to infest germinating white and chestnut oak acorns (Gibson 1964, Gibson 1971, Gibson 1972). Most authors fail to mention the presence of *Conotrachelus* weevils in northern red oak or indicate that they are so rare as to be incidental (Brooks 1910, Brezner 1960, Dorsey *et al.* 1962). However, very meticulous examination of acorn crops has revealed that small numbers of *Conotrachelus* weevils can be found in damaged northern red oak acorns in the fall (Gibson 1964, Gibson 1982, Galford *et al.* 1988). They followed infestation by other insects or attacked acorns with cracked or mammal-damaged shells. Research conducted in the spring on germinating northern red oak acorns has indicated that *Conotrachelus* weevils, particularly *C. posticatus*, can be serious pests (Galford *et al.* 1988, Galford *et al.* 1991a). In addition to their habit of breeding in the cotyledons of acorns, these weevils cause considerable damage to the shoots and radicles of germinating acorns.

The acorn moth, *Valentinia glandulella*, has been reported by many authors to be a scavenger of acorns vacated by primary pests such as *Curculio* weevils (Winston 1956, Brezner 1960, Gibson 1971, Gibson 1972). It was originally assumed that the larvae of this species fed only on the frass and detritus left behind in acorns by other insects. However, Gibson (1972) suggested that *Valentinia* larvae could cause additional damage to the acorn if during their foraging they consumed the remainder of the cotyledons. Subsequently, this species has variously been described as a secondary invader of acorns (Gibson 1982), a primary pest of germinating acorns (Galford 1986), and a primary invader of sound immature acorns (Galford *et al.* 1991a). The life cycle of this species has not been widely reported; however, some basic information is available. In the fall, the adult moth seeks out damaged acorns that have fallen to the ground and deposits eggs on or in cracks and other openings in the acorn shell (Williams 1989). When the larvae hatch, they enter the acorn, spin a web over the opening, and then feed on the remainder of the embryo, the frass of the previous occupant, and other materials, such as fungi, that may be present (Winston 1956, Williams 1989). It has been suggested that the larvae overwinter as early instars (Galford *et al.* 1991a). Winston (1956) reports that maturation may take up to a year but indicates that this may be partially controlled by the availability of food. Williams (1989) and Gibson (1972) both report that *Valentinia glandulella* pupates in the nut but no indication of the duration of the pupal period is given.

Valentinia glandulella has not been found to be a particularly important pest of acorns in the fall; however, because this species has until recently been considered primarily a scavenger, some researchers may have neglected to report their findings of it. Other authors have lumped *Valentinia* and *Melissopus* together in reports of infestations by lepidopterous larvae (Myers 1978, Gibson 1982). In one of the few studies in which lepidopterous larvae were separated by species, *Valentinia glandulella* was found in 38 of 283 collections of upland oak acorns made in West Virginia and was found to infest 0.5-11% of each collection (Dorsey *et al.* 1962).

Recently, Galford (1986) found *Valentinia glandulella* to be a serious pest of sound chestnut, white, and northern red oak acorns as they germinated. The larvae consumed emerging radicle tips as the acorns germinated or gained entrance to acorns as the seed coats split and fed on the outer surfaces of the cotyledons (Galford 1986, Galford *et al.* 1988). Since the larvae did not destroy the hypocotyl, which links the developing radicle with the cotyledon, it was suggested that some of the acorns may have retained their viability. In fact, many apparently healthy seedlings were produced in this study from *Valentinia*-infested acorns. The authors suggested that the only significant impact of this moth on northern red oak regeneration might be the attraction of more serious pests such as nitidulid beetles and *Conotrachelus* weevils.

Of the three species of sap beetles in the genus *Stelidota* found in the United States, only *Stelidota octomaculata* is considered a serious pest of northern red oak acorns (Galford *et al.* 1991b). Adults of this species become active in early spring when northern red oak acorns begin to germinate. They feed extensively on the emerging radicles and then breed in the cotyledons of the acorns as the shells split (Galford *et al.* 1988). This beetle can completely destroy an acorn and, in Ohio, was found to be one of the most serious pests of germinating northern red oak acorns. Krajicek (1960) reports that sap beetles (presumably *S. octomaculata*) were found in Iowa associated with northern red oak acorns that began germination but did not produce seedlings

Only limited information is available on the effects of these insects on northern red oak regeneration. Their most serious impacts can be expected during germination; however, most investigations of acorn insects have been conducted in the fall before red oak acorns begin to germinate. Recently, some work has been completed by Galford *et al.* (1991a) in Pennsylvania on germinating acorns. They found that 92% of surface-sown and 8% of buried northern red oak acorns that were protected from mammal predation were damaged by this group of insects. Buried acorns were destroyed by weevils and sap beetles that burrowed down through loose soil. In a study conducted the following year, insects damaged or destroyed 64% of northern red oak seedlings and 63% of germinating acorns (Galford *et al.* 1991a). Of the 1800 acorns used in that study, only 13% produced healthy seedlings.

The purpose of the present study was to determine if the same degree of damage could be expected on highly productive sites in West Virginia and to further determine if insect infestation was the cause of diminished seedling vigor on the less successful site. The effect of acorn burial on insect infestation was also examined.

METHODS

Study Site

This study was conducted on the West Virginia University Forest located in north-central West Virginia along the westernmost range of the Allegheny Mountains. This 7600-acre experimental forest is part of the Coopers Rock State Forest which straddles Interstate 68 in Monongalia and Preston Counties.

Two study sites were selected. The first site was located in the Lick Run watershed of the Forest where cove hardwood stands were selected on a northeast-facing slope. This study area was characterized by very high site indices for northern red oak (81 to 97), an abundance of mature yellow-poplar and northern red oak, and a moderate ground cover of herbaceous and woody vegetation. The SAF cover type was yellow-poplar--white oak--northern red oak (Eyre 1980). This site was located on a mid-slope position with an average slope of 12% (McNeel 1993). The soils are Dekalb stony sandy loams (Baur 1959). This study area will henceforth be referred to as the Lick Run site.

The second site was located in the Glade Run watershed of the Forest. The stands selected in this area were located on a drier northwest-facing slope and were characterized by lower site indices for northern red oak (68 to 73), a relative absence of yellow-poplar, a significant component of mature black cherry, and sparse ground cover. The SAF cover type on this site was also yellow-poplar--white oak--northern red oak (Eyre 1980). This site was located on a higher mid-slope position with an average slope of 17% (McNeel 1993). Soils were Dekalb stony sandy loams; however, the A horizons were thinner and contained more stone than those on the Lick Run site. This study area will henceforth be referred to as the Glade Run site.

Plot Establishment

Paired square plots of 0.5 acre were established on each site in May and June of 1990. The plots were isolated by a buffer strip on each side. Due to constraints imposed by a concurrent study, three pairs of plots were located on the Lick Run site and only two pairs were located on the Glade Run site. Each plot was divided into quarters and a mature (> 12 inches dbh), mast-producing, dominant or codominant northern red oak was located within each quarter. Therefore, a total of 40 trees (4 on each plot) were selected for study.

A cluster of three 1-foot square quadrats was randomly located within the area under the crown of each study tree. One of the quadrats in each cluster was fully enclosed with 0.5-inch mesh hardware cloth to exclude all potential mammalian and avian predators. These exclosures were constructed with mesh bottoms to prevent predators from entering from below and served as controls in the small mammal study. The tops of the exclosures were hinged so that they could be opened for observation. The remaining two quadrats were fully or partially accessible to small rodents and other mammalian predators and were not used in the present study.

Acorn Collection and Preparation

In 1990 and 1991, northern red oak acorns were collected off- site from a variety of locations in West Virginia and western Maryland from mid-September to late October of each year. The acorns were thoroughly mixed and then tested for viability at least 3 times over a period of 2 weeks using the float method (Korstian 1927, Schopmeyer 1974). Acorns that floated in water, had caps attached (indicating premature absiccsion), were damaged or discolored, or had insect exit holes or ovipositor scars were discarded. All acorns were stored in an unheated root cellar until use.

In the final year of study, acorns were collected on the study area. In mid-October 1993, all acorns, regardless of apparent condition, were manually collected from the ground under the crown of each of the 40 study trees. Acorns collected under the 4 study trees on each plot were then combined to provide a representative sample of acorns produced on each plot. These acorns were floated at least 3 times during a 2-week period and rejected acorns were set aside for use in another portion of the study.

Field Survival and Germination

In early November of 1990, 1991, and 1993, 9 apparently sound, undamaged acorns were placed on each quadrat in a square grid pattern. Nine acorns per quadrat was determined to be a reasonable approximation of that naturally occurring on a 1-foot square area (Gysel 1957). The acorns were pressed slightly into the humus to prevent them from rolling but were not buried. To assess the effect of burial on acorn survival, additional acorns were planted one inch deep in mineral soil on each quadrat. In 1990, only 3 acorns were buried; however, in 1991 and 1993, 9 acorns were buried. Therefore, there were a total of 12 acorns sown on each quadrat in 1990, 9 surface-sown and 3 buried, for a total of 60 acorns on each plot. In 1991 and 1993, a total of 18 acorns were sown on each quadrat, half on the surface and half buried, for a total of 72 acorns per plot. Leaf litter was placed over the acorns and the exclosures were wired shut and left undisturbed until the following spring. Around May 31 of each year, the exclosures were opened and the vigor of each seedling was rated 0 to 4 (Table 1).

Table 1. Seedling vigor rating descriptions

Rating	Description
0	Did not germinate
1	Germinated but weak root system, root or shoot dieback; not likely to survive
2	Strong root system, shoot small or just forming, generally earlier in development than seedlings with a rating of 3 or 4
3	Strong root system, no true leaves but strong healthy shoot
4	Same as a rating 3 seedling but at least one set of true leaves present

In 1994, any failed acorns and the seedlings with attached cotyledons were dissected with anvil shears. Insect damage or presence, disease, and apparent desiccation were recorded. In addition, the cotyledons were quartered and percent damage was estimated. All larvae present were collected and preserved in 80% ethanol for later identification.

RESULTS

Seedling Vigor in All Three Years of Study

Mean seedling vigor on each quadrat was calculated by year and treatment. Overall means by watershed are shown in Table 2. Analysis of variance revealed that mean vigor was significantly higher on the Lick Run site in all 3 years of study ($F = 22.60$ $Pr > F = 0.0001$),. In addition, year ($F = 21.16$, $Pr > F = 0.0001$) and treatment ($F = 29.21$, $Pr > F = 0.0001$) were found by the main effects model to significantly affect seedling vigor; however, there was also a significant year by treatment interaction ($F=14.18$, $Pr > F = 0.0001$). Examination of the interaction using additional ANOVA's and t-tests indicated that treatment was only significant in 1992 ($T = 6.16$, $Pr > |T| = 0.0001$). In that year, seedlings produced by buried acorns on both sites were more vigorous than those produced by surface-sown acorns. Among just the buried acorns, there was no significant difference between seedling vigor in 1992 and 1994, although vigor in both of these years was significantly higher than that observed in 1991 ($F = 15.04$, $Pr > F = 0.0001$). Among just surface-sown acorns, there was significantly higher vigor in 1994 than in either 1991 or 1992 ($F=16.77$, $Pr > F = 0.0001$). This was apparent on both sites but was more important on the Glade Run watershed. Average vigor in 1991 and 1992 on this site was 1.3 and 1.7, respectively, indicating that very few acorns were able to produce viable seedlings in either year. Seedling vigor rose to 2.6 in 1994, suggesting that the average seedling was healthy, well-developed, and capable of surviving. This was quite apparent in the field, as quadrats and entire plots that did not produce a single seedling in the previous years of study were found to be highly successful in 1994. On the Lick Run site, average vigor in 1991 was 2.3, in 1992 was 2.0, and in 1994 was 3.0. Healthy, viable seedlings were produced in all 3 years on this site; those produced in 1994 were exceptionally vigorous.

Table 2. Mean seedling vigor by year, watershed, and treatment.

Year	Site	Treatment	No. quadrats	Mean Vigor	Standard Error
1991	Lick Run	Surface	24	2.3	0.18
		Buried	24	2.3	0.17
	Glade Run	Surface	16	1.3	0.12
		Buried	16	2.0	0.24
1992	Lick Run	Surface	24	2.0	0.18
		Buried	24	3.3	0.15
	Glade Run	Surface	16	1.7	0.24
		Buried	16	2.8	0.25
1994	Lick Run	Surface	24	3.0	0.18
		Buried	24	3.0	0.11
	Glade Run	Surface	16	2.6	0.11
		Buried	16	2.7	0.15

Overall Insect-Infestation Rates on the Two Sites in 1994

In 1994, 56.9% of the 216 surface-sown acorns on the Lick Run site were sound. Twenty-seven percent had been at least partially damaged by insects, 5.6% were diseased, and the remainder exhibited damage due to root or shoot dieback (3.4%), desiccation (0.4%), surface mold (0.4%), or unknown causes (0.4%) (Figure 1). Most of the insect damage was caused by *Conotrachelus* weevils, although *Valentinia* moth larvae, and very small numbers of nitidulid sap beetles and fly maggots were identified (Figure 1). In contrast, 49.1% of the surface-sown acorns on the Glade Run site were sound, 24.8% were insect damaged, 10.3% were affected by root and shoot dieback, 8.5% were diseased and 1.8% were desiccated. Again, *Conotrachelus* weevil larvae were responsible for most of the insect damage (Figure 1). In general, buried acorns fared much better. On both sites, approximately 76% of the buried acorns were undamaged and approximately 10% were insect damaged. Root and shoot dieback affected 1.7% of the germinating acorns on the Lick Run site and 2.1% on the Glade Run site. Just under 9% of the acorns on the Glade Run site and 5.3% of those on the Lick Run site appeared to be diseased; however, the isolation of pathogens was not attempted (Figure 1).

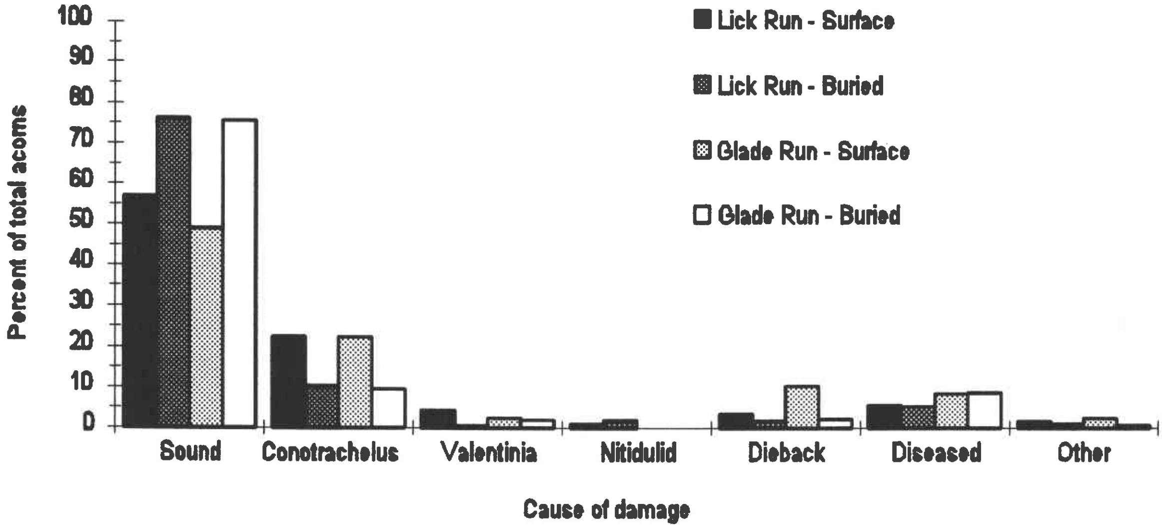

Figure 1. Total percentages of sound and damaged acorns by site, treatment, and damaging agent. Note: these are pooled percentages and are not based on the quadrat-level means used in the analysis of variance.

Comparison of Insect Infestation Between Sites in 1994

To allow comparison of insect infestation between the sites, percent infestation by any insect or combination of insects was calculated by treatment on each quadrat. Acorns infested by more than one insect were counted only once in this analysis and those infested by fly maggots were excluded as they appeared to have succumbed to disease before infestation. Analysis of variance on these data revealed that insect infestation did not vary by site ($F = 0.31$, $Pr > F = 0.5824$); however, there was a significant treatment effect ($F = 4.69$, $Pr > F = 0.0335$) with no site by treatment interaction. On average, surface-sown acorns were about twice as likely to be infested regardless of site (Table 3). Infestation rates on individual quadrats within the sites were quite variable.

Table 3. Mean percent of acorns infested by insects on each plot in 1994 by site and treatment.

Site	Teatment	No. plots	Mean infestation rate (%)	Range on individual quadrats (%)	Standard error. (%)
Lick Run	Buried	6	11.6	0-44	1.2
	Surface-sown	6	24.1	0-100	7.4
Glade Run	Buried	4	10.4	0-44	2.3
	Surface-sown	4	19.4	0-89	7.4

Cotyledon Damage and Seedling Vigor in 1994

Each acorn was classified as sound, insect-infested, or damaged by other agents. Mean vigor and mean percent cotyledon damage were then calculated by group and treatment on each quadrat. Analysis of variance indicated that there were significant differences in vigor among the groups ($F = 139.58$, $Pr > F = 0.0001$). Seedlings from sound acorns were found by Fisher's LSD comparisons to be significantly more vigorous than those produced by damaged acorns, regardless of damaging agent, site, or treatment. In addition, acorns damaged by insects produced significantly more vigorous seedlings than those damaged by other agents such as desiccation and disease. Differences in seedling vigor are obvious in the pooled data (Figure 2).

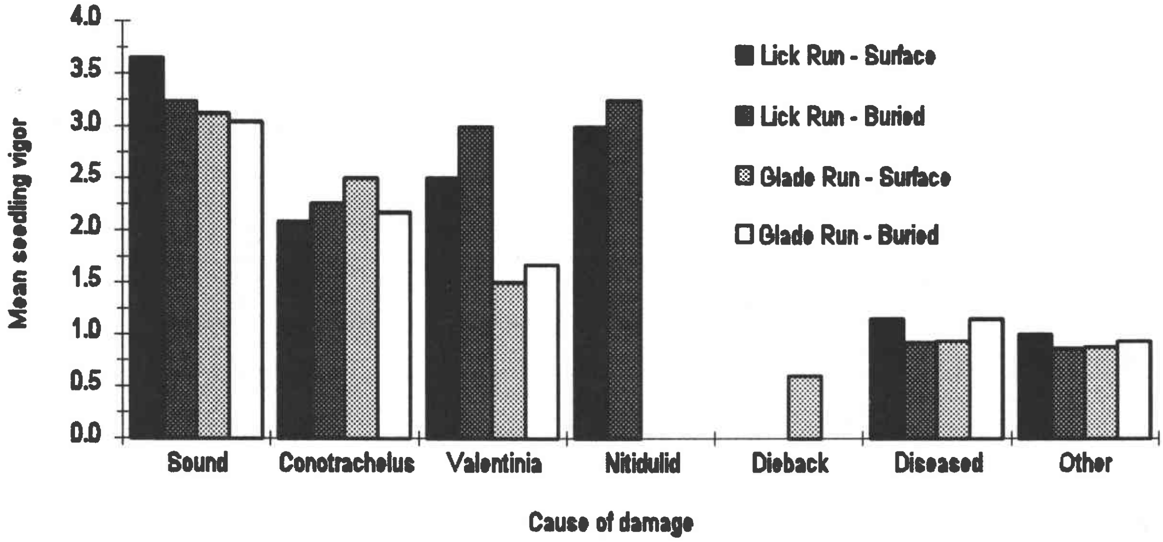

Figure 2. Average vigor of sound and damaged acorns by site, treatment, and damaging agent. Note: these means are calculated using all of the data pooled by site and treatment and are not based on the quadrat-level means used in the analysis of variance.

An additional ANOVA was conducted to determine if desiccation and disease resulted in more extensive cotyledon damage than did insects. This analysis, which excluded sound acorns, revealed that percent cotyledon damage was significantly higher in acorns damaged by agents other than insects ($F = 19.24$, $Pr > F = 0.0001$). Cotyledon damage due to insects averaged 14.8% (SE=2.5%) while that caused by other agents averaged 38.9% (SE=5.0%). Site and treatment had no significant impact on the degree of cotyledon damage observed in either group of acorns.

These results suggested that percent cotyledon damage could be used to improve the original analysis of variance on vigor. Therefore, percent cotyledon damage by all agents was used as a covariate with site and treatment in an analysis of covariance. This analysis demonstrated that percent cotyledon damage was significantly related to seedling vigor ($F = 8.06$, $Pr > F = 0.0060$) and that it explained some of the variation within site (Figure 3). There was no significant treatment effect.

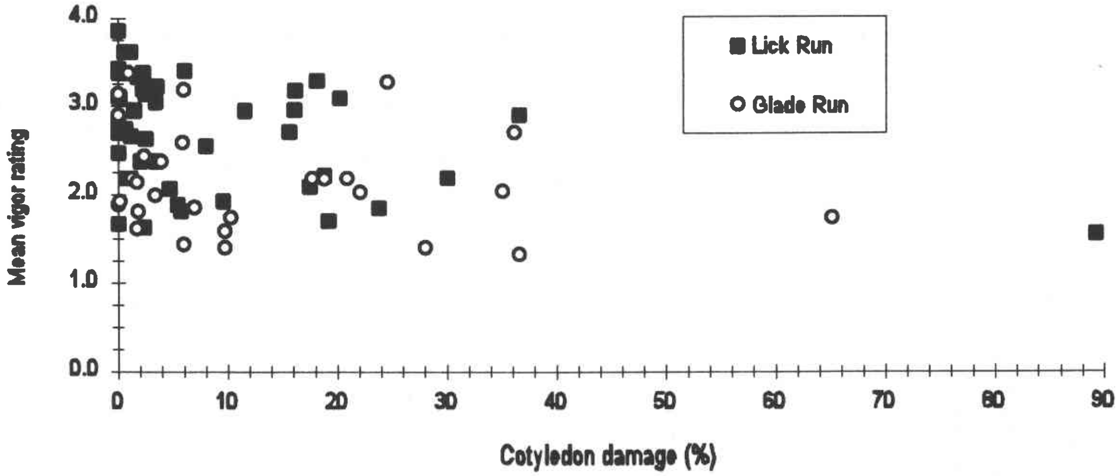

Figure 3. Mean seedling vigor versus mean cotyledon damage by site. Each observation is based on a single quadrat.

DISCUSSION

Seedling vigor was consistently better on the Lick Run site regardless of the year of study, indicating that the additional data pertaining to acorn condition and damage collected in 1994 could be expected to have at least some relevance to the results from the previous two years. However, vigor was found to be significantly higher among surface-sown acorns on both sites in 1994, indicating that growing conditions were not consistent across the 3 years. This annual variation, likely weather related, cannot be accounted for with a single year of study. Therefore, it is unlikely that the cause of the widespread failure observed on the Glade Run site in 1991 and 1992 can be determined here. However, initial data on the incidence of insects in germinating northern red oak acorns can be reported for north-central West Virginia. In addition, the effects of these insects on seedling vigor in a year of high reproductive success can be examined.

The results of the 1994 study indicate that all three of the insects noted to be serious pests of germinating northern red oak acorns in Ohio (Galford *et al.* 1988) and Pennsylvania (Galford *et al.* 1991a) were also present in north-central West Virginia. In concurrence with the results of both of these studies, *Conotrachelus* weevils were the most serious pest of germinating acorns. The *Valentinia* moth was much less prevalent. In addition, the incidence of moth larvae was not uniform across the study area. This species appeared sporadically in individual quadrats and usually infested several acorns in each affected quadrat. *Valentinia* moth larvae have not been previously reported to infest buried acorns; however, in this study, small numbers were found feeding in buried acorns on both sites (Figure 1).

The nitidulid sap beetle was almost absent from the study area. Cotyledon damage due to the feeding and breeding activities of adult sap beetles was extremely minor in the few acorns infested on the Lick Run site. As suggested by Galford et al. (1991a), sap beetles may not have been active by late May when the acorns and seedlings were collected from the field. Their possible impact later in the growing season deserves more study, as sap beetles were found capable of widespread seedling damage in Ohio (Galford *et al.* 1988).

Overall, the incidence of acorn pests in germinating northern red oak acorns was much lower than that reported in the Ohio and Pennsylvania studies. However, weather conditions were quite unusual in West Virginia during the winter of 1993-94. A relatively wet fall was followed by an extremely cold winter with much greater than normal snowfall. A hard crusty snowpack remained on the study area almost constantly throughout the winter. Spring came late and hard frosts were still occurring in mid- to late May. However, by May 30-31, when the exclosures were opened, daytime temperatures had exceeded 70°F for several days and the ground was beginning to warm. In contrast, the winters of 1991 and 1992 were very mild with sporadic snowfall and only patchy accumulations of snow on the study area. In both of these years there was unseasonably warm weather in late February when temperatures ranged from 60°F to 70°F for a week to 10 days.

In 1991 and 1992, acorns in the study area began germinating by late February; however, in 1994, germination did not begin until mid-April. Galford *et al.* (1991a) found larval acorn moths in Pennsylvania to become active in germinating acorns by mid-February, weevil larvae to commence feeding by mid-March, and sap beetles to begin activity in late May. The hard winter and late spring in West Virginia in 1994 may have delayed emergence of the insects and it is possible that insects had not begun to emerge until shortly before the exclosures were opened. In addition, the late germination of the acorn crop may have resulted in a lack of suitable habitat for insects that did emerge early. In the case of the sap beetle, it appears that breeding was delayed. The few acorns that were infested by nitidulids showed only minimal oviposition damage and no larvae were present. Had the study been continued into the summer, sap beetles, and perhaps late-emerging weevils and acorn moths, may have had more of an impact.

In addition, Galford *et al.* (1991a) indicate that most acorns infested by insects in central Pennsylvania were completely destroyed and were incapable of producing viable seedlings. This was not the case in the present study. Although insect infestation and resultant cotyledon damage did reduce seedling vigor, they were not severe enough in most cases to cause lack of seedling success. The fact that insect infestation on average resulted in only 14.8% cotyledon damage and that larvae were still present in most infested cotyledons indicates that the adult insects may have emerged too late to have more than a minimal impact on the rapidly growing seedlings.

Of even more significance is the lack of difference in percent insect infestation between the sites, even though the seedlings on the Glade Run site were again found to be less vigorous. It was initially hypothesized that the lack of seedling success and vigor on the Glade Run site was due in part to insect infestation; however, at least in 1994, this was not the case. As mentioned previously, the widespread reproductive failure observed on the Glade Run site in 1991 and 1992 was absent in 1994. Glade Run acorns produced healthy seedlings in 1994, although they were in general smaller and less well-developed than those produced on the Lick Run site. This appeared to be a microsite effect, perhaps caused by the warmer, drier northwest aspect or more exposed slope position of the Glade Run site.

Several corollaries can now be put forth to explain the acorn failure on the Glade Run site. First, if insect infestation and effect is assumed to have been similar on both sites in the previous two years of study, then some other factor must have been responsible for the lack of seedling production. This factor may have been desiccation as the Glade Run site is drier and more exposed than the Lick Run site. Or the acorns may have become diseased. Winston (1956) and Dorsey *et al.*(1962) identified several bacterial and fungal agents that may affect acorn viability even in the absence of insect infestation. Overall, desiccation and disease were found to be slightly more prevalent on the Glade Run site (Figure 1), although there were not sufficient numbers of desiccated or diseased acorns to allow statistical analysis. Both were found in this study to cause almost complete cotyledon destruction and loss of acorn viability. No seedlings were produced by desiccated acorns and the seedlings produced by diseased acorns exhibited a notable lack of vigor (Figure 2). Since the winters of 1991 and 1992 were relatively dry with a lack of snowpack, widespread desiccation on the Glade Run site is a particularly good possibility.

Conversely, the relatively minimal effects of insects in 1994 may have been an anomaly. Populations may usually be higher on one or both sites. If this was the case in 1991 and 1992, feeding in the cotyledons may have been more extensive and in itself may have caused more notable lack of vigor or may have predisposed acorns to failure due to drying or disease. Several more years of study on a greater number of sites would provide additional insight.

SUMMARY

It has been established that *Conotrachelus* weevils, the acorn moth, *Valentinia glandulella*, and the nitidulid sap beetle, *Stelidota octomaculata*, infest germinating northern red oak acorns in north-central West Virginia. The data from a single year of study indicate that these insects were much less prevalent and much less damaging on this study site than they were on sites in Ohio and Pennsylvania. However, the severity of the winter of 1994 and the late spring frosts may have resulted in delayed emergence.

It is suspected that agents other than insects were responsible for the acorn failure and lack of vigor noted in 1991 and 1992. Disease and desiccation, when they did occur, almost invariably caused acorn failure in 1994. These factors may have had more widespread effects in the previous years of study and warrant additional study in future years.

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