Effects of Clone, Silvicultural, and Miticide Treatments on Cottonwood Leafcurl Mite (Acari: Eriophyidae) Damage in Plantation *Populus*

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ABSTRACT *Aculops lobuliferus* (Keifer) is a little known pest of plantation *Populus* spp., which is capable of causing substantial damage. This is the first documented occurrence of *A. lobuliferus* in South Carolina. Previous anecdotal data indicated clonal variation in *Populus* susceptibility to *A. lobuliferus* damage. A damage rating scale was created to monitor mite damage in 2000–2001 in a short-rotation woody crop plantation; damage descriptions and seasonal phenology also were recorded. Foliar damage and terminal mortality were monitored on two *Populus deltoides* Bartr. clones, ST66 and S7C15, receiving one of three silvicultural treatments (irrigated [I], fertilized [F], or I+F) or no treatment (control). In 2001, early season foliar damage ratings were significantly higher on clone S7C15; however, damage on clone ST66 was greater after miticide treatments later in the year. Terminal mortality did not differ between clones. Silvicultural treatment significantly affected foliar damage levels in both clones. Trees receiving I+F and F treatments had higher damage ratings than did trees receiving irrigation alone or the control at times. Clone S7C15 trees receiving fertilizer had significantly less terminal mortality than their nonfertilized counterparts. Application of a commercially available miticide significantly reduced *A. lobuliferus* damage levels. This study demonstrates that *A. lobuliferus* damage levels can be influenced by *Populus* clone and silvicultural treatment. Foliar and terminal damage levels observed in this study indicate the potential for substantial economic impact of *A. lobuliferus* on plantation *Populus*. Although an effective control method may be to select and plant resistant *Populus* clones, chemical control remains a viable option.

KEY WORDS *Aculops lobuliferus*, defoliation, intensive forestry, *Populus deltoides*, terminal mortality

ERIOPHYID MITES (Acari: Eriophyoidea) are a large and diverse group of great economic importance in agricultural and forestry systems (Jeppson et al. 1975, Briones and McDaniel 1976, Keifer et al. 1982, Lindquist et al. 1996). Although some species attack nonwoody plants, most are pests of trees and shrubs (Briones and McDaniel 1976), specifically *Populus* spp. (Wilson and Oldfield 1966). Forty eriophyid mite species are pests on 14 *Populus* spp. worldwide (Amrine and Stasny 1994) including 11 eriophyid species on 6 *Populus* species in the United States (Baker et al. 1996).

Aculops lobuliferus (formerly *Aculus* sp.) (Keifer) (Keifer 1961, 1966) is an eriophyid mite commonly infesting eastern cottonwood, *Populus deltoides* Bartr. (Salicales: Salicaceae) (Davis et al. 1982). Common names include the cottonwood leafcurl mite and cottonwood rust mite (Morris et al. 1975, Briones and McDaniel 1976, Ostry et al. 1989). This mite feeds primarily on young, succulent leaves on branch terminals (Morris et al. 1975, Ostry et al. 1989). It has two alternating life forms: an actively feeding form (protogyne) and a hibernating form that seeks refuge in bark crevices or at the base of the tree trunk (deutogyne) (Morris et al. 1975). All life stages can be found together on foliage. *A. lobuliferus* has previously been positively identified in only four states: Mississippi, Ohio, South Dakota, and West Virginia (Davis et al. 1982, Baker et al. 1996).

Initial *A. lobuliferus* damage appears as vein and leaf reddening, leaf curling, and a scaly coating on petioles and terminal buds (Morris et al. 1975, Ostry et al. 1989). Heavy or prolonged damage can result in premature defoliation, terminal mortality, reduced growth, and tree mortality (Morris et al. 1975). Heavy damage has been reported on young *P. deltoides* nursery trees (Jeppson et al. 1975, Baker et al. 1996). However, most of the existing literature deals only with taxonomy. No published information exists on *A. lobuliferus* population or damage levels, preference and performance on different *Populus* clones, damage in intensively cultured plantations, nor has its interaction with varying levels of host resource availability been assessed.

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Short-rotation woody crop (SRWC) systems use agricultural techniques to accelerate tree growth and have the potential to provide wood pulp and products faster than traditional forestry (Dickmann and Stuart 1983). During the 2000–2001 growing seasons, an *A. lobuliferus* outbreak on a SRWC *Populus* plantation in South Carolina provided an opportunity to examine several aspects of *A. lobuliferus* biology, as well as its interactions with *P. deltoides.* Because of the paucity of data on this pest, the first objective of this study was to describe *A. lobuliferus* damage and its seasonal phenology. The second objective was to compare the susceptibility of two *Populus* clones to *A. lobuliferus* damage. *Populus* clonal differences are apparent for several arthropod pests (Caldbeck et al. 1978, Nordman 1998, Coyle et al. 2001) and pathogens (Newcombe et al. 1994). It was hypothesized that the two clones would differ in their susceptibility to *A. lobuliferus* damage. The third objective was to evaluate *A. lobuliferus* responses to the silvicultural treatments applied to the two *Populus* clones. More vigorous trees produce greater quantities of new growth, thus providing a greater quantity of fresh food to mites and encouraging higher populations (Jeppson et al. 1975). Following the plant vigor hypothesis (Price 1991), I hypothesized that the highest damage levels would occur in high-resource treatments. The fourth objective was to evaluate the efficacy of Kelthane MF, a commercially available miticide, on *A. lobuliferus.* Monocultural plantings often increase the chances of pest outbreaks because of reduced natural enemy habitat and the overabundance of pest food (Root 1973, Nowak and Berisford 2000, Zhang et al. 2000). Previous researchers attained excellent *A. lobuliferus* control using other Kelthane formulations and general insecticides (Newsome and Solomon 1980).

Materials and Methods

Experimental Design. This study was conducted on the U.S. Department of Energy Savannah River Site, a National Environmental Research Park, located near Aiken, SC (33° 23′ N, 81° 40′ E). Two *P. deltoides* clones (ST66 and S7C15 of Mississippi and eastern Texas origin, respectively) were planted as dormant cuttings in April 2000 into Blanton series soils (Rogers 1990). Three silvicultural treatments were used: irrigated (I) at 3.0 cm/wk, fertilized (F) at 120 kg N/yr, and irrigated + fertilized (I+F) at the aforementioned rates. A nonirrigated, nonfertilized control also was included in the experimental design. Irrigation and liquid fertilizer (7:7:7 N:P:K + micronutrients in 2000, 7:5:8 N:P:K without micronutrients in 2001) were provided via an automated trickle irrigation system. The 2^2 factorial experiment consisted of three blocks, each containing one plot per treatment per clone. Trees were planted at 3 × 2.5 m spacing in 0.2-ha (0.54 acre) plots; each plot contained 294 trees. Weeds were controlled during the study using pre- and postemergent herbicides (Goal 2XL, Rohm and Haas, Philadelphia; and Roundup PRO, Monsanto, St. Louis), rotary tillers, and mowers. Surrounding vegetation was roughly 30-yr-old upland pine with a sparse oak understory.

Miticide Treatments. 2000 Growing Season. Kelthane 50 (51% [AI] dicofol; Rohm and Haas, Philadelphia) was sprayed on 21–22 September 2000 at a rate of 0.38 liter/ha (5.1 oz/acre). Spraying was directed at infested branch terminals on both clones under all treatments with a wand sprayer mounted on an all-terrain vehicle.

2001 Growing Season. Kelthane MF (42% [AI] dicofol; Rohm and Haas) was first applied to both clones under all treatments on 5 and 10 May, and again on 15 and 20 August 2001, at a rate of 7.10 liter/ha (96 oz/acre). Two miticide applications were required at 5–7-d intervals to control mites and newly hatched eggs, respectively. Each dual miticide application is referred to as a miticide treatment. All applications were made with an AF500-CPS orchard sprayer (Durand-Wayland, LaGrange, GA) set to deliver 1741 liter/ha (180 gal/acre).

Damage Measurements. 2000 Growing Season. Observational data were taken during 2000. The timing of initiation and duration of the mite infestation, approximate foliar damage and population levels, and estimated *Populus* growth reduction (premature abscission and bud set) were recorded.

2001 Growing Season. Measurements in 2001 included the timing of initiation and duration of the mite infestation, as well as damage ratings and terminal mortality. All data were recorded from the interior six trees per plot; $n = 18$ for each clone × treatment combination. Damage ratings were taken on leaf plastochron index (LPI) 0–12 (Larson and Isebrands 1971) of the main terminal on each measurement tree before and 2 wk after the first miticide treatment (5 and 24 May 2001, respectively). The LPI is a leaf numbering system whereby the newest leaf on a terminal with a lamina length >3 cm is designated as LPI 0. Leaves with smaller lamina lengths are given consecutive negative numbers in the direction of the branch terminal. Positive numbers are assigned to leaves in the direction of the main stem.

Damage ratings were taken several times before and after the second miticide treatment at weekly and/or bi-weekly intervals (6, 22, and 28 July; 3, 11, and 27 August; 11 and 25 September). The following damage scale was used: 0, no damage; 1, light redness in leaf veins only, slight leaf curling; 2, heavy redness in leaf veins and slight redness between veins, substantial leaf curling; 3, leaves dark red to brown, completely curled, crunchy to the touch; 4, all above symptoms, <25% defoliation; 5, all above symptoms, 25–50% defoliation; 6, all above symptoms, >75% defoliation, dead terminal. The percentage of all first-order and stem terminals killed by mites in 2000 was recorded for each measurement tree on 5 May 2001. Mite-killed terminals were identified by a scaly, crusted appearance.

Statistical Analyses. Measurements in 2000 were strictly observational, so only 2001 damage ratings and terminal mortality data were analyzed. Data were analyzed separately after each miticide treatment as a 2^2

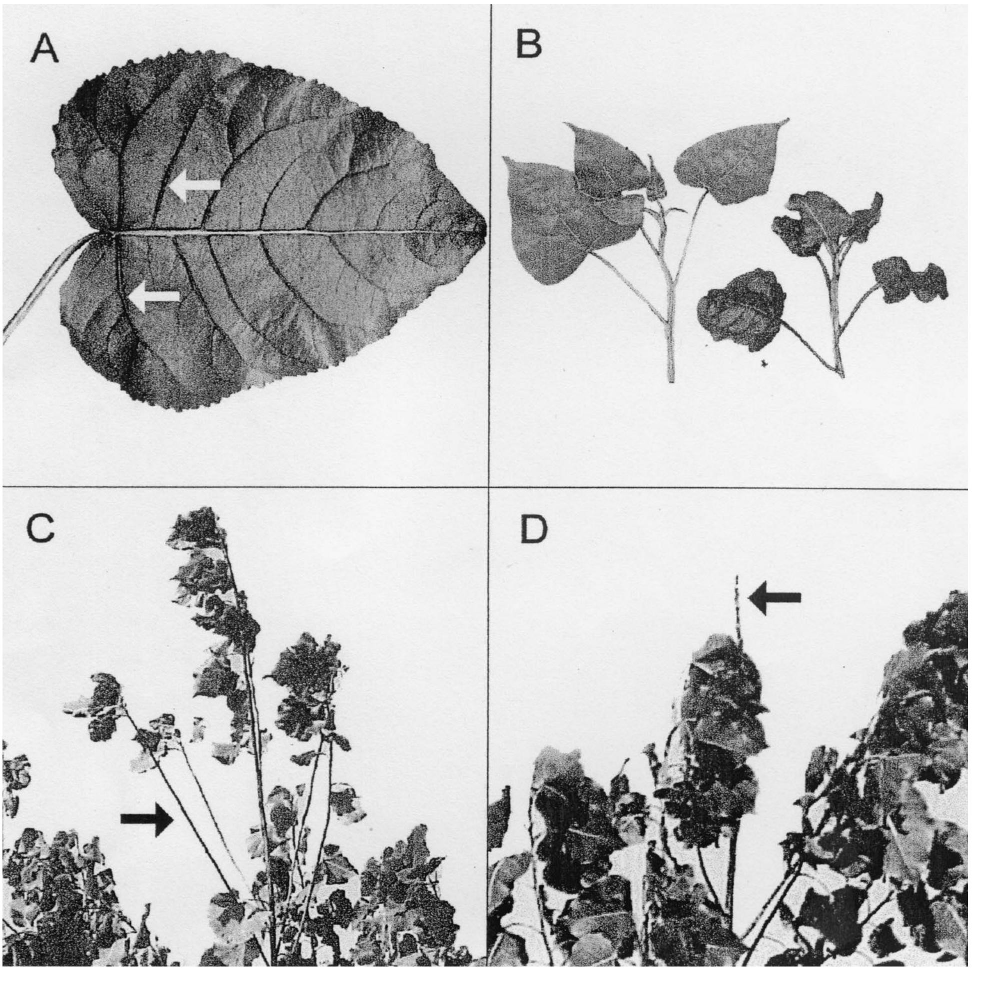

Fig. 1. *Aculops lobuliferus* damage to *Populus deltoides*. (A) Early damage to *P. deltoides* leaf caused by *A. lobuliferus* feeding. Arrows point to darkened (red) veins. Note slight curling on the leaf edges. (B) A resistant (left) and susceptible (right) *P. deltoides* shoot. Leaves on the resistant shoot are light green in color and uncurled, whereas leaves on the susceptible shoot are red to purple in color and curling at the edges. (C) *Populus deltoides* tree exhibiting the effect of previous *A. lobuliferus* damage. The arrow points to where premature leaf abscission has occurred on large areas of the stem and branches. The tree resumed leaf production after a miticide application. (D) A *P. deltoides* terminal (arrow) killed as a result of heavy *A. lobuliferus* damage.

factorial design. The PROC GLM analysis method (SAS Institute 1999) was used to analyze foliar damage ratings on individual days to examine pre- and post-miticide differences between clone and among treatments. Leaf damage ratings before and after miticide treatments were analyzed using the PROC MIXED repeated-measures analysis (SAS Institute 1999) to evaluate miticide efficacy. Terminal mortality data were arcsine transformed to assume a normal distribution (Zar 1999) and were analyzed using the PROC MIXED method. Contrast comparisons were used to examine the effects of irrigation, fertilization, and the irrigation × fertilization interaction within each clone. Means were separated with the Tukey honestly significant difference (HSD) test (SAS Institute 1999).

Results

Damage Description. The entire range of *A. lobuliferus* damage included leaf discoloration, curling, premature leaf abscission, and terminal mortality. The primary leaves affected were those on LPI 0–12. Initial damage appeared as slightly-to-moderately red midribs and primary veins on leaves (Fig. 1A). The reddening pattern originated in the midrib and extended outward on the primary veins; color intensity was greatest at the midrib. This color pattern intensified and spread into nonvein areas until the entire leaf had taken on a reddish-purple color (Fig. 1B). Leaf curling was synonymous with the foliar color change. Leaves often curled to the point that the edges touched each other on the ventral side of the leaf. As leaf color change and curling increased, the petioles and stem became scaly and crusty visually and to the touch. Infested leaves often were smaller than those on non-infested shoots.

As older leaves became discolored, curled, and scaly, leaf abscission followed. This process took from several days in high mite populations to >2 wk in low populations. When mite populations were low, the tree added new leaves to the terminal and prematurely abscised lower leaves on the shoot at a similar rate. This resulted in branches and stems having large areas without leaves, while retaining a cluster of new expanding leaves on the terminal (Fig. 1C). Under high populations, leaves showing all stages of damage could be found on a single branch at any one time.

Extremely high mite populations expanded at a rate greater than that of tree growth. Leaves never fully expanded because they were discolored and curled as soon as they began expanding from the terminal. Under these conditions terminal mortality often occurred as mites presumably fed on and in the leaf terminal, possibly killing leaves before they expanded (Fig. 1D). Infestations also caused premature bud set on many lateral branches and several terminals.

Seasonal Phenology. 2000 Growing Season. *A. lobuliferus* infestations were first noted the week of 24 July and lasted until tree senescence in early November. Infestations and damage levels peaked and stabilized in mid-September. *A. lobuliferus* population levels were high with the mites appearing as a moderate-to-heavy yellow dust on leaves. Silvicultural treatment differences were not obvious, however clonal differences in susceptibility were evident. Clone S7C15 appeared much more susceptible than clone ST66, particularly when comparing premature defoliation amounts and foliar damage levels. Clone S7C15 had a much higher incidence of premature bud set, particularly on lateral terminals, but also on several main terminals. Bud set on both clones began in early September. The miticide treatment resulted in no noticeable decline in mite population levels or damage. Observed damage ratings during peak infestation levels (September–November) would have averaged 5–6 on S7C15 and 4–5 on ST66 had the damage rating scale been implemented.

2001 Growing Season. Unlike the first growing season (2000), *A. lobuliferus* appeared concurrently with *P. deltoides* budbreak in the second year. The first damage was noticed during the second week of April 2001. Damage steadily increased until the first miticide treatment. This eliminated all signs of *A. lobuliferus* on both clones until late July when the populations and damage began increasing. The second miticide treatment reduced *A. lobuliferus* populations and damage, but not to the extent of the first application. Small pockets of *A. lobuliferus* survived the treatment, but did not spread throughout the plantation. These isolated populations persisted until early November when fall leaf senescence began.

Clonal Effects. Based on damage ratings, significant clonal differences in susceptibility to *A. lobuliferus* were apparent before and after the May 2001 miticide treatment (Table 1). Initial damage ratings on clone S7C15 were more than three times higher than on ST66 (Table 1). Damage on clone ST66 consisted primarily of minor foliar curling and slight discoloration, whereas damage on S7C15 ranged from heavy curling and discoloration to brittle leaves and occasional leaf loss. Postmiticide damage measurements were more than twice as high on clone S7C15 than on ST66 (Table 1), but were generally quite low.

Table 1. *Populus* clonal effects on *A. lobuliferus* foliar damage and mean (± SE) damage ratings during the 2001 growing season

Date	F	df	P	Clone ST66	Clone S7C15
5 May	59.51	1,136	****	0.42 ± 0.06	1.47 ± 0.13
24 May	11.72	1,136	***	0.14 ± 0.04	0.37 ± 0.06
6 July	29.32	1,136	****	0.36 ± 0.05	0 ± 0
11 August	155.48	1,136	****	2.81 ± 0.13	0.54 ± 0.12
24 September	8.75	1,136	**	0.49 ± 0.07	0.21 ± 0.08

****, $P < 0.0001$; ***, $P = 0.0001$ to 0.0009; **, $P = 0.001$ to 0.009; *, $P = 0.01$ to 0.05.

Damage measurements on 6 July 2001 indicated one of two things: a shift in clonal susceptibility or a change in mite feeding preference (Fig. 2). No *A. lobuliferus* damage was observed on clone S7C15; and for the first time, damage ratings on clone ST66, although quite low, were significantly higher than on S7C15 (Table 1). The greatest amount of damage occurred in August; this was evident by the foliar damage ratings taken on the peak infestation date (11 August). Damage levels on clone ST66 were more than five times greater than on S7C15 (Table 1). Damage on clone S7C15 remained relatively low, appearing as foliar discoloration and slight curling. However, damage on clone ST66 included very brittle, deeply discolored leaves, large areas of premature leaf abscission on the stem and branches, and the first evidence of terminal mortality during the 2001 growing season. On 24 September, damage was low on both clones, but ratings on clone ST66 were more than twice as high as on S7C15 (Table 1).

Terminal mortality was nearly identical on the two clones and did not differ significantly ($F = 0.09$; df = 1, 136; $P = 0.7664$). Mean (±SE) percent terminal mortality was 14.29 ± 3.19 on clone ST66 and 15.54 ± 2.83 on S7C15.

Silvicultural Treatment Effects. There were no silvicultural treatment differences in foliar damage ratings before the first miticide treatment in either clone in 2001 (Table 2). Postmiticide damage levels were significantly affected by treatment in clone S7C15 but not ST66 (Table 2). Damage was more than twice as high on fertilized compared with nonfertilized treatments (Table 2), and foliar damage levels in the I+F treatment were significantly higher than those in the I treatment and control (Fig. 2). This pattern was present before the miticide treatment on clone S7C15.

Clone ST66 foliar damage ratings on 6 July 2001 were significantly affected by treatment and were higher in the I+F than the F treatment (Fig. 2). No damage was observed on clone S7C15 on 6 July (Fig. 2). Silvicultural treatment differences in damage

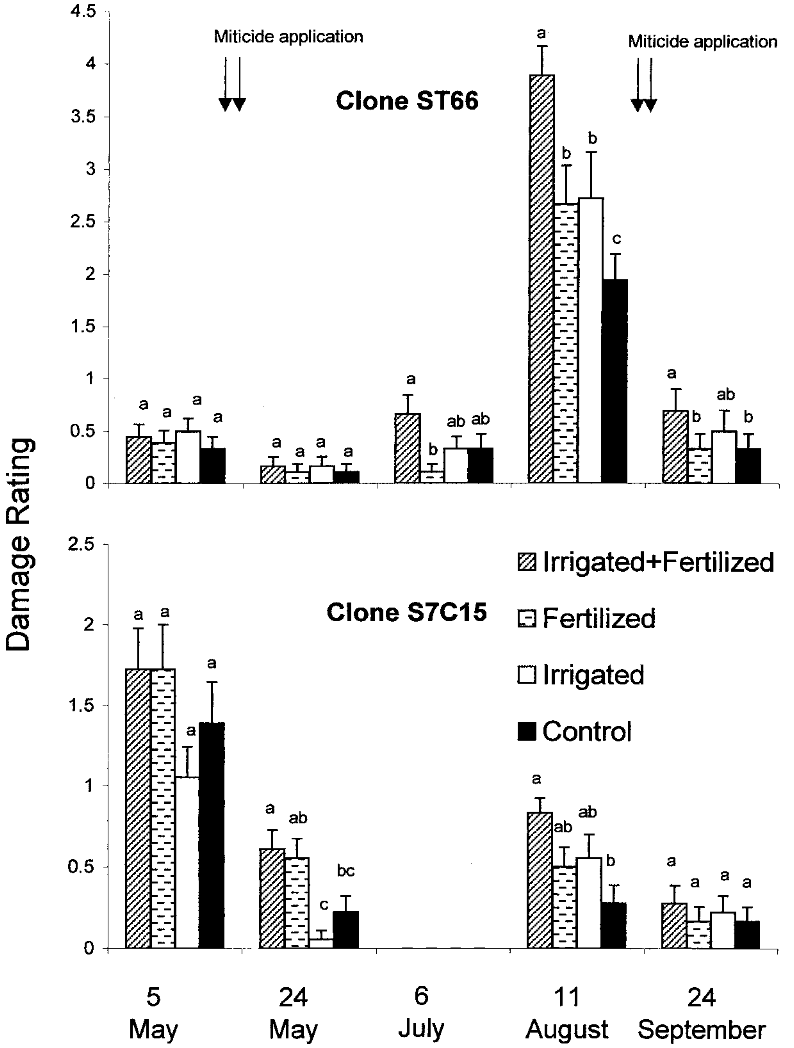

Fig. 2. *Aculops lobuliferus* damage ratings on two *P. deltoides* clones each receiving four fertigation treatments in the 2001 growing season. Means (± SE) sharing a letter within a clone × date are not significantly different (Tukey HSD; $\alpha = 0.05$).

levels during peak infestation on 11 August were significant for both clones (Table 2). Damage levels in the I+F treatment were significantly higher than in the control treatment on both clones (Fig. 2). Foliar damage ratings were more than four times higher in the I+F treatment on clone ST66 than on S7C15. Additionally, foliar damage ratings in the I+F and control treatments were significantly higher and lower, respectively, than in the F and I treatments for clone ST66. Foliar damage ratings in the I+F treatment for clone ST66 were double those in the control treatment. Irrigation of clone S7C15 significantly increased damage levels (Table 2). Treatment differences among final damage ratings on 24 September were significant for clone ST66 only (Table 2; Fig. 2). Damage levels in the I+F treatment were significantly higher than in the F and control treatments for clone ST66 (Fig. 2). Treatment effects were not significant for clone S7C15 (Table 2), and overall damage ratings were low.

Terminal mortality did not differ significantly among silvicultural treatments for clone ST66 (F = 1.30; df = 3, 60; P = 0.2829) as means (±SE) ranged from 18.83 ± 7.76 in the F treatment to 10.76 ± 2.90 in the I+F treatment. However, silvicultural treatment significantly affected terminal mortality in clone S7C15 (F = 4.25; df = 3, 60; P = 0.0086). Contrast comparisons indicated that fertilized trees (F and I+F treatments) in clone S7C15 had significantly lower terminal mortality than nonfertilized trees (I and control treatments) (F = 15.99; df = 1, 6; P = 0.0071). Percent terminal mortality in I and control treatments

Table 2. Silvicultural treatment effects on *A. lobuliferus* foliar damage ratings for two *P. deltoides* clones during the 2001 growing season

Date	Clone	Effect	*F*	df	*P*
5 May	ST66	Silvicultural treatment	0.38	3, 60	ns
		Fert	0.00	1, 6	ns
		Irr	0.91	1, 6	ns
		Fert + Irr	0.23	1, 6	ns
	S7C15	Silvicultural treatment	1.82	3, 60	ns
		Fert	0.41	1, 6	ns
		Irr	3.72	1, 6	ns
		Fert + Irr	0.41	1, 6	ns
24 May	ST66	Silvicultural treatment	0.15	3, 60	ns
		Fert	0.39	1, 6	ns
		Irr	0.00	1, 6	ns
		Fert + Irr	0.00	1, 6	ns
	S7C15	Silvicultural treatment	7.61	3, 59	***
		Fert	0.15	1, 6	ns
		Irr	7.66	1, 6	*
		Fert + Irr	0.54	1, 6	ns
6 July	ST66	Silvicultural treatment	3.62	3, 60	*
		Fert	2.56	1, 6	ns
		Irr	0.10	1, 6	ns
		Fert + Irr	2.56	1, 6	ns
	S7C15	Silvicultural treatment	N/A	3, 60	N/A
		Fert	N/A	1, 6	N/A
		Irr	N/A	1, 6	N/A
		Fert + Irr	N/A	1, 6	N/A
11 August	ST66	Silvicultural treatment	17.47	3, 60	****
		Fert	3.16	1, 6	ns
		Irr	2.82	1, 6	ns
		Fert + Irr	0.16	1, 6	ns
	S7C15	Silvicultural treatment	3.64	3, 60	*
		Fert	7.72	1, 6	*
		Irr	5.17	1, 6	ns
		Fert + Irr	0.06	1, 6	ns
24 September	ST66	Silvicultural treatment	3.45	3, 60	*
		Fert	1.70	1, 6	ns
		Irr	0.44	1, 6	ns
		Fert + Irr	0.44	1, 6	ns
	S7C15	Silvicultural treatment	0.30	3, 60	ns
		Fert	0.61	1, 6	ns
		Irr	0.07	1, 6	ns
		Fert + Irr	0.07	1, 6	ns

****, $P < 0.0001$; ***, $P = 0.0001$ to 0.0009; **, $P = 0.001$ to 0.009; *, $P = 0.01$ to 0.05; ns, not significant.

(22.67 ± 8.58 and 16.38 ± 4.57, respectively) was significantly higher than in the I+F (14.01 ± 4.55) or F (9.12 ± 3.58) treatment.

Miticide Efficacy. The May ($F = 105.49$; df = 1, 259; $P < 0.0001$) and August ($F = 163.53$; df = 1, 259; $P < 0.0001$) miticide treatments significantly reduced *A. lobuliferus* foliar damage ratings on both clones (Fig. 2) and under all silvicultural treatments.

Discussion

Seasonal Phenology. The major difference between mite populations in 2000 and 2001 was the time of initial infestation. This may be due to tree size or age, because the 1-yr-old trees (planted in April 2000) were much smaller and had less leaf area than the 2-yr-old trees. No studies have examined the overwintering biology of *A. lobuliferus.* Several eriophyid species are known to overwinter under bud scales (Krantz 1978), and this may to be the case with *A. lobuliferus* because mite populations appeared concurrently with *Populus* budbreak in 2001. However, Morris et al. (1975) suggested that *A. lobuliferus* hibernates in bark, branch scars, or at the base of the tree. All of these appear to be viable possibilities.

Presumably, mites did not appear concurrently with budbreak in 2000 as they did in 2001 because of the time required to find this new food source. *A. lobuliferus* may feed unnoticed on an alternative host more closely associated with our study site. Keifer (1966) described four new *Aculops* spp. , including one from Florida, whose hosts include sumac (*Rhus* spp.) and willow (*Salix* spp.). Other rust mite (genera *Aculops* or *Aculus*) hosts are tomato, *Lycopersicon* spp. (Leite et al. 1999); filberts, *Corylus* spp. (Krantz 1973); and bamboo, *Phyllostachy* spp. (Zhang et al. 2000). Sumac and willow are present at the study plantation, and tomatoes and bamboo are present within 5 km of our study site. One or all of these species may potentially serve as an alternative host for *A. lobuliferus.*

No studies have examined *A. lobuliferus* dispersal, but the method is most likely aerial as has been documented in other eriophyid species on grasses (Nault and Styer 1969), in filbert orchards (Krantz 1973), and in citrus groves (Bergh 2001). The nearest *Populus* plantations were >60 km away, and no wild *Populus* grew within 3 km of our plantation. This suggests that, if used, the aerial dispersal capabilities of this mite are great, possibly covering many miles.

Clonal Effects. During the 2000 season and in May 2001, greater amounts of *A. lobuliferus* damage occurred on clone S7C15. However, higher damage levels occurred on clone ST66 after the May 2001 miticide treatment. Whether or not this is a shift in clonal susceptibility (previously undocumented for *Populus* arthropod pests) or a change in mite feeding preference is unknown and is surprising because both clones received identical cultural, chemical, and silvicultural treatments. Regardless of whether the host shift or change in preference exhibited by *A. lobuliferus* was environmentally, ecologically, or physiologically induced, it will be important to identify the cause of this phenomenon to make informed decisions about pest management.

Foliar damage, but not terminal mortality, differed on the two clones used in this study. *Populus* spp. are host to numerous insect pests (Nordman 1998, Mattson et al. 2001, Coyle et al. 2002b). Many, including the cottonwood leaf beetle, *Chrysomela scripta* F., (Coleoptera: Chrysomelidae) (Caldbeck et al. 1978), forest tent caterpillar, *Malacosoma disstria* Hübner (Lepidoptera: Lasiocampidae), and gypsy moth, *Lymantria dispar* L. (Lepidoptera: Lymantriidae) (Hwang and Lindroth 1997) show preference for or against certain *Populus* clones. The identification of *Populus* clones resistant or tolerant to *A. lobuliferus* foliar and terminal damage will be an important component in developing a sound integrated pest management (IPM) plan for this pest.

Silvicultural Treatment Effects. *A. lobuliferus* responses to silvicultural treatments did not become apparent until 24 May on clone S7C15 and 6 July on clone ST66 (Fig. 2). Foliar damage levels, although not always significant, were always numerically highest in the high resource (I+F) treatment. The highest *A. lobuliferus* damage levels on 11 August 2001 followed the expected high-to-low resource treatment stratification for both clones, and damage levels in the I+F treatment were significantly higher than in the other silvicultural treatments. These results support the plant vigor hypothesis in that greater quantities of new foliage are produced on more vigorous plants providing more suitable food to phytophagous pests and encouraging population increases (Price 1991).

A. lobuliferus damage levels were greater in the I+F treatment on both clones than in the fertilized treatment. With the exception of the May measurements on clone S7C15, higher damage levels occurred in the irrigated than control treatments; this pattern was true in every instance on clone ST66. These results suggest that *A. lobuliferus* may respond negatively to drought conditions. Water stress induced by high temperatures and drought contributed to a sharp decline in *Aculus comatus* (Nalepa) populations in filbert, *Corylus maxima,* orchards (Krantz 1973). Three mite species each responded differently to induced drought conditions in a lime orchard: *Phyllocoptruta oleivora* (Ashmead) populations fluctuated widely, *Brevipalpus phoenicis* populations were not affected by, and *Tetranychus mexicanus* Koch. populations increased after a 6-wk drought (Quiros-Gonzalez 2000).

Intensive management, including herbicide, fertilizer, and irrigation applications, may greatly increase tree growth rates and yields (Stanturf et al. 2001). However, the effects of these silvicultural treatments may vary for each pest species. For instance, increased nitrogen and potassium had only a minor influence on *Aculops lycopersici* (Massee) population levels on tomato plants (Leite et al. 1999). Herbicide, irrigation, and fertilization treatments had minimal effects on Nantucket pine tip moth, *Rhyacionia frustrana* (Comstock) (Lepidoptera: Tortricidae), damage levels in a loblolly pine, *Pinus taeda,* plantation; whereas southern pine coneworm, *Dioryctria amatella* (Hulst) (Lepidoptera: Pyralidae), damage was greatest in the most intensive silvicultural treatment (Nowak and Berisford 2000). The resource concentration hypothesis (Root 1973) states that increased pest populations and outbreaks are more likely in monocultural plantings because of the large quantities of food present. Mite damage in China was consistently higher in bamboo monocultures compared with polycultures (Zhang et al. 2000). Although this study did not compare *Populus* monocultures and polycultures, damage in intensively managed plantations is expected to be greater than that of polycultures or native *Populus* stands.

Miticide Efficacy. The miticide application in 2000 resulted in no noticeable decline in *A. lobuliferus* damage. It appeared that all susceptible foliage did not receive adequate miticide coverage when the directed spray application method was used. In contrast, we achieved excellent *A. lobuliferus* control in 2001, presumably because of the more thorough miticide application produced by the high-volume orchard sprayer. Two miticide treatments were applied in 2001 that resulted in successful control. *A. lobuliferus* damage was not observed during the month of June, most likely because of the excellent control attained by the miticide treatment in May. However, although damage levels dropped significantly after the August treatment (Fig. 2), they did not descend to the level previously attained using the same miticide.

There is potential for *A. lobuliferus* to develop resistance to dicofol, and sound pest management tactics must include alternating miticide formulations when possible. Regular dicofol use for *P. oleivora* management led to a buildup of resistance in those populations (Omoto et al. 1994). Dicofol-resistant *Tetranychus urticae* Koch expressed avoidance behavior toward the miticide and increased locomotory activity (Kolmes et al. 1994). Other pesticides have proven effective in controlling *A. lobuliferus* (Newsome and Solomon 1980). Currently, synthetic chemical application is the method most commonly used for commercial control of *A. lobuliferus.* However, several management strategies are available when dealing with pests in monocultural systems. If *Populus* clones resistant or tolerant to *A. lobuliferus* become available, clonal rotations or polycultures may become alternative management strategies (Coyle et al. 2002b).

In conclusion, *Aculops lobuliferus* has the potential to be a very important economic pest in all regions where it occurs. For instance, one *Populus* clone has already been removed from commercial production in Missouri because of its high susceptibility to *A. lobuliferus* (R. J. Rousseau, personal communication). Our plantation had high population and damage levels in the first and second years of the study. The resulting damage most likely would have been substantial had miticide not been applied. Repeated defoliation significantly decreased *Populus* growth and nitrate uptake (Kosola et al. 2001), and after only 3 yr reduced above-ground stem volume by as much as 73% in some *Populus* clones (Coyle et al. 2002a). This represents a substantial economic loss.

Many research opportunities exist for *A. lobuliferus*, a species that has received little attention since its discovery in 1961. This mite probably exists in small populations on wild *P. deltoides* stands. The use of *Populus* species for plantation forestry was in its infancy until the late 1980s and has recently grown to >22,000 ha in the Pacific Northwest alone (Stanton et al. 2002). *A. lobuliferus* is most likely cosmopolitan in distribution across the United States and has shown rapid population increases in plantation *Populus*. Results from this study indicate that *A. lobuliferus* has the potential to become a major arthropod pest of plantation *Populus*. Terminal mortality in plantation *Populus* is very damaging to tree form and growth; these factors can be directly correlated with the tree's monetary value.

Intensive plantation management may disrupt the natural balance between pests and predators. Natural enemy populations may control *A. lobuliferus* populations in native *Populus* stands, however populations appear to prosper in the monocultural environment created by SRWC systems. Biological control methods are unknown, yet effective chemical control methods exist (Newsome and Solomon 1980). Ultimately, an effective IPM plan for *A. lobuliferus* should be developed if intensively managed *Populus* plantations are to provide wood and pulp products for society.

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References Cited

Amrine, J. W., Jr., and T. A. Stasny. 1994. Catalog of the Eriophyoidea (Acarina: Prostigmata) of the world. Indira Publishing House, West Bloomfield, MI.

Baker, E. W., T. Kono, J. W. Amrine, Jr., M. Delfinado-Baker, and T. A. Stasny. 1996. Eriophyid Mites of the United States. Indira Publishing House, West Bloomfield, MI.

Bergh, J. C. 2001. Ecology and aerobiology of dispersing citrus rust mites (Acari: Eriophidae) in central Florida. Environ. Entomol. 30: 318–326.

Briones, M. L., and B. McDaniel. 1976. Eriophyid plant mites of South Dakota. S.D. Agric. Exp. Stn. Tech. Bull. 43.

Caldbeck, E. S., H. S. McNabb, Jr., and E. R. Hart. 1978. Poplar clonal preferences of the cottonwood leaf beetle. J. Econ. Entomol. 71: 518–520.

Coyle, D. R., J. D. McMillin, R. B. Hall, and E. R. Hart. 2001. Cottonwood leaf beetle (Coleoptera: Chrysomelidae) larval performance on eight *Populus* clones. Environ. Entomol. 30: 748–756.

Coyle, D. R., J. D. McMillin, R. B. Hall, and E. R. Hart. 2002a. Cottonwood leaf beetle (Coleoptera: Chrysomelidae) defoliation impact on *Populus* growth and above-ground volume in a short rotation woody crop plantation. Agric. For. Entomol. 4: 293–300.

Coyle, D. R., J. D. McMillin, R. B. Hall, and E. R. Hart. 2002b. Deployment of tree resistance to insects in short-rotation *Populus* plantations, pp. 187–213. *In* M. R. Wagner, K. M. Clancy, F. Lieutier, and T. D. Paine [Eds.], Mechanisms and Deployment of Resistance in Trees to Insects. Kluwer Academic, New York.

Davis, R., C.H.W. Flechtmann, J. H. Boczek, and H. E. Barké. 1982. Catalogue of Eriophyid Mites (Acari: Eriophyoidea). Warsaw Agricultural University Press, Warsaw, Poland.

Dickmann, D. I., and K. W. Stuart. 1983. The Culture of Poplars in Eastern North America. Michigan State University Press, Lansing.

Hwang, S.-Y., and R. L. Lindroth. 1997. Clonal variation in foliar chemistry of aspen: effects on gypsy moths and forest tent caterpillars. Oecologia 111: 99–108.

Jeppson, L. R., H. H. Keifer, and E. W. Baker. 1975. Mites Injurious to Economic Plants. University of California Press, Los Angeles.

Keifer, H. H. 1961. Eriophyid studies B-2. Special Publication, 1 May. State Bureau of Entomology, California Department of Agriculture 20 p., Sacramento, CA.

Keifer, H. H. 1966. Eriophyid studies B-21. Special Publication, 23 Nov. State Bureau of Entomology, California Department of Agriculture. Sacramento, CA.

Keifer, H. H., E. W. Baker, T. Kono, M. Delfinado, and W. E. Styer. 1982. An Illustrated Guide to Plant Abnormalities Caused by Eriophyid Mites in North America. U.S. Dep. Agric. Agric. Handb. 573.

Kolmes, S. A., T. J. Dennehy, and Y. Sam. 1994. Contrasting behavior of twospotted spider mites (Acari: Tetranychidae) on discontinuous residues of a pyrethroid and a chlorinated hydrocarbon acaricide. J. Econ. Entomol. 87: 559–565.

Kosola, K. R., D. I. Dickmann, E. A. Paul, and D. Parry. 2001. Repeated insect defoliation effects on growth, nitrogen acquisition, carbohydrates, and root demography of poplars. Oecologia 129: 65–74.

Krantz, G. W. 1973. Observations on the morphology and behavior of the filbert rust mite, *Aculus comatus* (Prostigmata: Eriophyoidea) in Oregon. Ann. Entomol. Soc. Am. 66: 709–717.

Krantz, G. W. 1978. A Manual of Acarology. 2nd edition. Oregon State University Press, Corvallis. 509 p.

Larson, P. R., and J. G. Isebrands. 1971. The plastochron index as applied to developmental studies of cottonwood. Can. J. For. Res. 1: 1–11.

Leite, G.L.D., M. Picanço, R.N.C. Guedes, and J. C. Zanuncio. 1999. Influence of canopy height and fertilization levels on the resistance of *Lycopersicon hirsutum* to *Aculops lycopersici* (Acari: Eriophyidae). Exp. Appl. Acar. 23: 633–642.

Lindquist, E. E., M. W. Sabelis, and J. Bruin. (eds.). 1996. Eriophyid mites—their biology, natural enemies, and control. World Crop Pests, vol. 6. Elsevier, New York.

Mattson, W. J., E. R. Hart, and W.J.A. Volney. 2001. Insect pests of *Populus:* coping with the inevitable, pp. 219–248. *In* D. I. Dickmann, J. G. Isebrands, J. E. Eckenwalder, and J. Richardson [Eds.], Poplar Culture in North America, Part A. NRC (National Res. Council) Res. Press, Ottawa, ON.

Morris, R. C., T. H. Filer, J. D. Solomon, F. I. McCracken, N. A. Overgaard, and M. J. Weiss. 1975. Insects and diseases of cottonwood. General Technical Report SO-8. USDA Forest Service, Southern Forest Experiment Station, New Orleans, LA.

Nault, L. R., and W. E. Styer. 1969. The dispersal of *Aceria tulipae* and three other grass-infesting eriophyid mites in Ohio. Ann. Entomol. Soc. Am. 62: 1446–1455.

Newcombe, G., G. A. Chastagner, W. Schutte, and B. J. Stanton. 1994. Mortality among hybrid poplar clones in a stool bed following leaf rust caused by *Melampsora medusae* f. sp. deltoidae. Can. J. For. Res. 24: 1984–1987.

Newsome, L., and J. D. Solomon. 1980. Control of eriophyid mites on cottonwood with foliar sprays. Insectic. Acaric. Tests 5: 187.

Nordman, E. E. 1998. Evaluation of willow and poplar biomass production clones for resistance to multiple insect pests. M.S. thesis, State University of New York, Syracuse.

Nowak, J. T., and C. W. Berisford. 2000. Effects of intensive forest management practices on insect infestation levels and loblolly pine growth. J. Econ. Entomol. 93: 336–341.

Omoto, C., T. J. Dennehy, C. W. McCoy, S. E. Crane, and J. W. Long. 1994. Detection and characterization of the interpopulation variation of citrus rust mite (Acari: Eriophyidae) resistance to dicofol in Florida citrus. J. Econ. Entomol. 87: 566–572.

Ostry, M. E., L. F. Wilson, H. S. McNabb, Jr., and L. M. Moore. 1989. A Guide to Insect, Disease, and Animal Pests of Poplars. U.S. Dep. Agric. Agric. Handb. 677.

Price, P. W. 1991. The plant vigor hypothesis and herbivore attack. Oikos 62: 244–251.

Quiros-Gonzalez, M. 2000. Phytophagous mite populations on Tahiti lime, *Citrus latifolia,* under induced drought conditions. Exp. Appl. Acarol. 24: 897–904.

Rogers, V. A. 1990. Soil Survey of Savannah River Plant area, parts of Aiken, Barnwell, and Allendale counties, South Carolina. USDA Soil Conservation Service, Washington DC.

Root, R. B. 1973. Organization of a plant-arthropod association in simple and diverse habits: the fauna of collards (*Brassica oleracea*). Ecol. Monogr. 43: 95–124.

SAS Institute. 1999. User's Manual. Version 8.1. SAS Institute, Cary, NC.

Stanton B., J. Eaton, J. Johnson, D. Rice, B. Schuette, and B. Moser. 2002. Hybrid poplar in the Pacific Northwest: the effects of market-driven management. J. For. 100: 28–33.

Stanturf, J. A., C. van Oosten, D. A. Netzer, M. D. Coleman, and C. J. Portwood. 2001. Ecology and silviculture of poplar plantations, pp. 153–206. *In* D. I. Dickmann, J. G. Isebrands, J. E. Eckenwalder, and J. Richardson [Eds.], Poplar culture in North America, Part A. NRC (National Res. Council) Res. Press, Ottawa, ON.

Wilson, N. S., and G. N. Oldfield. 1966. New species of Eriophyid mites from western North America, with a discussion of eriophyid mites on *Populus.* Ann. Entomol. Soc. Am. 59: 585–599.

Zar, J. H. 1999. Biostatistical analysis, 4th ed. Prentice Hall, New York.

Zhang, Y., Z-Q. Zhang, L-X. Tong, Q. Liu, and M. Song. 2000. Causes of mite pest outbreaks in bamboo forests in Fujian, China: analyses of mite damage in monoculture versus polyculture stands. Syst. Appl. Acarol. 4: 93–108.

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