Research Reports

Artillery Fungus Sporulation on 27 Different Mulches — A Field Study[1]

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Abstract

During the last decade, the 'artillery fungus' has emerged from an interesting mycological curiosity that grows in landscape mulch to a problem of major financial concern to homeowners, insurance companies, mulch producers, and landscape contractors. This common inhabitant of landscape mulch produces sticky spore masses (gleba) that it shoots towards the light or towards reflective objects such as light-colored automobiles or house siding. We evaluated 27 different mulches in the field to determine their ability to support growth and sporulation of the artillery fungus. Each mulch type was inoculated in 1998 with the artillery fungus and the amount of sporulation (number of spore masses on targets) determined annually until 2002, approximately 4 years after inoculation. We grouped the 27 mulches into nine general categories that had common characteristics: mulches that originated from large piles of bark and wood mixtures, mulches blended with 5% compost, cedar mulch, mulches commercially designated as 'bark' but containing considerable wood, dyed wood chips, non-dyed wood chips, cypress mulch, large bark nuggets, and 100% spent mushroom substrate. The mulches obtained from large piles shredded blends of bark and wood supported significantly greater levels of artillery fungus sporulation than did other mulches. Such highly susceptible mulches should be avoided if the artillery fungus is to be minimized. In contrast, large bark nuggets, cypress mulch, and 100% spent mushroom substrate supported less artillery fungus. Other mulches supported intermediate levels of sporulation. All wood/bark landscape mulches will eventually support the artillery fungus over extended time periods (*i.e.*, 3–4 years), and even more tolerant mulches should be replaced or covered with a fresh layer of mulch on a regular basis.

Index words: *Sphaerobolus stellatus*, *Sphaerobolus iowensis*, mulch, black spots.

Significance to the Nursery Industry

In recent years, homeowner complaints regarding artillery fungus have increased. This fungus lives in landscape mulch and shoots its sticky spore mass (gleba) towards light-colored reflective house siding, as well as other light surfaces including sides of automobiles. The attached gleba turn dark and are very difficult to remove from the surface where they land and adhere. Even if they can be removed, a dark brown stain remains. Thousands of gleba on the sides of houses may result in insurance claims being filed for painting or replacing disfigured house siding. However, if insurance companies deny such a claim, the liability may shift to the mulch producer, mulch sales yard, or contractor applying the mulch. The objectives of this field study were to evaluate 27 different mulches to determine their ability to support the artillery

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fungus, and to provide recommendations to homeowners, as well as to mulch and landscaping industries, regarding which mulches could be used to minimize the artillery fungus problem. Mulch from large commercial mulch piles, comprised of composting mixtures of shredded bark and wood, supported significantly greater levels of artillery fungus sporulation than did other mulches. Such highly susceptible mulches should be avoided if the artillery fungus is to be minimized. In contrast, large bark nuggets, cypress mulch, and 100% spent mushroom substrate supported less artillery fungus. Other mulches supported intermediate levels of sporulation. Almost all wood/bark mulches will eventually support the artillery fungus over extended time periods (*i.e.*, 3–4 years), and even more tolerant mulches should be replaced, or covered with a fresh layer of mulch, on a regular basis.

Introduction

Landscape mulches are used to maintain soil moisture, reduce weeds, and enhance aesthetics. In the past, mulches often were composed of tree bark, obtained mainly from sawmills that debarked trees. However, modern mulches are usually constructed from wood, or wood and bark blends. Sources of current mulches include sawmills, land clearing operations, and recycling facilities (4, 6, 8, 9). Modern mulch is often shredded to a fine texture, may be artificially dyed, and may even be blended with organic waste products. Many different types of fungi, including the artillery fungus, inhabit mulch (3, 10).

The term 'artillery fungus' refers to two species of *Sphaerobolus*: *S. stellatus* and *S. iowensis*. Our research was conducted only with *S. stellatus*. The artillery fungus is a white-rot, wood-decay Basidiomycete that can grow on most types of damp organic matter (11). During colonization of wood and bark substrates, the artillery fungus first consumes cellulose and hemicellulose, leaving behind the N-rich lignin-humus complex. As the fungus later uses the lignin, the mulch becomes lighter in color, characteristic of a white-rot fungus. Moist, rotting landscape mulch appears to be an ideal substrate for growth of the artillery fungus, especially foundation mulches located on the cool, north sides of houses (3). As the substrate is consumed, sporulation occurs during cool, wet periods of spring and fall.

During sporulation, the artillery fungus produces sticky gleba (spore masses) that it shoots towards the light or light-colored reflective objects (11, 17). The gleba adhere tightly to surfaces such as house siding (13) or automobiles (19), turn dark, and are difficult to remove without leaving an unsightly stain, resulting in complaints by homeowners. Because this adherence and staining is associated with the mulch, many homeowners complain to their mulch producers and landscape contractors, as well as their homeowners insurance company.

Based on the distribution of complaints fielded by the authors, in the United States this problem appears to be most severe in the Northeast where the cool, moist climate is likely conducive for growth and sporulation of this fungus in spring and fall. The artillery fungus was especially severe in eastern United States during the prolonged wet periods from spring to fall of 2003. However, the authors have received samples of the artillery fungus and/or complaints from Alaska to various locations on the East Coast from Florida to Maine. In addition, the artillery fungus grows in many other regions of the world (3).

The reasons for the recent, rapid rise in notoriety are unknown. Wider recognition and awareness of the artillery fungus by the public certainly has led to a perceived increase in the problem. However, other factors that have recently favored the artillery fungus may include: increased use of landscape mulch; possible introduction of new strains or species that more readily colonize mulch and/or sporulate at greater levels; and recent changes in mulch composition more suitable to the artillery fungus.

Our research is concerned mainly with the last possibility. In an initial study, we previously reported that several different landscape mulches support different levels of sporulation by the artillery fungus (3). However, the field plots in that study were destroyed by a severe storm prior to its planned completion, curtailing the most critical part of the experiment. Nevertheless, initial results from that study led us to hypothesize that recent increases in the artillery fungus were indeed related, at least in part, to recent changes in the composition of landscape mulches from primarily bark to primarily wood.

The specific objective of this study was to evaluate the ability of 27 mulches to support sporulation by the artillery fungus in the field. Some of these mulches had been evaluated in a preliminary manner within our initial study (3), and this is an expansion of that project. Our overall objective was to make recommendations to the mulch and landscaping industries, as well as homeowners, regarding mulches that might be used to discourage this objectionable fungus.

Materials and Methods

Types of mulch. Eastern white pine (*Pinus strobus* L.), northern red oak (*Quercus rubra* L.), and yellow-poplar or tuliptree (*Liriodendron tulipifera* L.) trees, *ca*. 25 cm (10 in) in diameter, were felled from a local wooded area in 1997. To obtain additional material, white oak (*Q. alba* L.), eastern white pine, and yellow-poplar trees of similar size were harvested from the same area in 1998. Bark was stripped from the felled trees and cut into pieces using hand-clippers; wood was passed through a commercial chipper. Both materials were sieved to obtain 2–3 cm (*ca*. 1 in.) diameter particles, air-dried in the greenhouse for 24 hrs, and stored in plastic bags at 15C (68F).

All other mulches were obtained in 1998. Plastic bags of 'cedar', 'cypress', and 'pine bark mini-nuggets' were purchased from local retail outlets. Although the bags did not list exact tree species used to produce these mulches, the cedar mulch appeared to originate from Atlantic white cedar (*Chamaecyparis thyoides* L. (B.S.P.)) and the cypress mulch from baldcypress (*Taxodium distichum* L.). Pine bark nuggets were apparently from various pine species. The five mulches were shoveled into large plastic bags from large, composting, yard piles of commercial mulch producers, identified as 'Producer #1 bark', 'Producer #1 bark and wood mix', 'Producer #2 bark', 'Producer #2 bark and wood mix', and 'Producer #3 wood, bark and yard waste'. However, the mulch products described as 'bark' mulch usually contained significant amounts of wood. These five mulches had been composting (and turned routinely) in large piles from midsummer 1997 until spring 1998.

Sewage and yard waste composts were obtained locally. The sewage waste compost consisted of sawdust mixed with wastewater biosolids (sludge) that had been composted for 2 months. The yard waste compost contained grass clippings,

Table 1. **Description of 27 mulches used in this study. Mulches were purchased in bags, shovelled from large mulch piles, or were prepared by the authors.**

Treat. no.	Mulch type	Mulch description	% N[z]	C:N ratio[z]
1	White pine wood, spring	Pure wood chips from 25–30 cm dia eastern white pine tree felled by authors in spring of 1998; chips passed through a 2–3 cm dia screen	0.04	1252
2	Yellow-poplar bark, fall	Nearly pure bark chips from 25–30 cm dia yellow-poplar tree felled by authors in fall of 1997; chips passed through a 2–3 cm dia screen	0.17	303
3	Red oak bark, fall	Nearly pure bark chips from 25–30 cm dia red oak tree felled by authors in fall of 1997; chips passed through a 2–3 cm dia screen	0.33	145
4	White pine bark, fall	Nearly pure bark chips from 25–30 cm dia eastern white pine tree felled by authors in fall of 1997; chips passed through a 2–3 cm dia screen	0.28	183
5	White oak bark, spring	Pure bark chips from 25–30 cm dia white oak tree felled by authors in spring of 1998; chips passed through a 2–3 cm dia screen; bark in small, flat flakes	0.28	170
6	White oak wood, spring	Pure wood chips from 25–30 cm dia white oak tree felled by authors in spring of 1998; chips passed through a 2–3 cm dia screen	0.07	687
7	Producer #1 wood & bark mix	Predominately wood, but contained significant amounts of bark; shredded; collected on-site by authors from producer's yard piles; derived from various tree species; double ground	0.24	200
8	Wood chips dyed brown	Air-dried pure white oak wood chips (2–3 cm dia) dyed by authors from commercial, concentrated-liquid dye	0.07	687
9	Wood chips dyed red	Air-dried pure white oak wood chips (2–3 cm dia) dyed by authors from commercial, concentrated-powder dye	0.07	687
10	5% sewage compost	Sawdust mixed with wastewater biosolids (sludge); composted for 2 months; obtained from local municipality		
11	Cypress	Stringy, wood and bark; finely shredded; purchased in bags from local retail outlets	0.12	420
12	Producer #1 'bark'	Predominately bark, but contained approx. 15% wood; shredded; collected by authors from producer's yard piles; derived from various tree species; double ground	0.40	121
13	Pine bark mini-nuggets	Mainly bark, but with small amount of attached wood; purchased in bags from local retail outlets	0.15	338
14	White pine wood, fall	Nearly pure wood chips from 25–30 cm dia white oak tree felled by authors in fall of 1997; chips passed through a 2–3 cm dia screen	0.12	407
15	Producer #2 wood & bark mix	Predominately wood, but contained significant amounts of bark; shredded; collected on-site by authors from producer's yard piles; derived from various tree species; double ground	0.17	280
16	Yellow-poplar bark, spring	Pure bark chips from 25–30 cm dia yellow-poplar tree felled by authors in spring of 1998; chips passed through a 2–3 cm dia screen	0.42	118
17	White pine bark, spring	Pure bark chips from 25–30 cm dia eastern white pine tree felled by authors in spring of 1998; chips passed through a 2–3 cm dia screen.	0.21	242
18	Yellow-poplar wood, spring	Pure wood chips from 25–30 cm dia yellow-poplar tree felled by authors in spring of 1998; chips passed through a 2–3 cm dia screen	0.07	684
19	Yellow-poplar wood, fall	Nearly pure wood chips from 25–30 cm dia yellow-poplar tree felled by authors in fall of 1997; chips passed through a 2–3 cm dia screen	0.02	2488
20	5% yard waste compost	Grass clippings, leaves, and chipped wood; composted for 3–4 months; obtained from local municipality	—	—
21	100% spent mushroom substrate	From a commercial mushroom house; consisted of steam-sterilized horse and chicken manure, gypsum, and a proprietary nutrient supplement	—	—
22	Red oak wood, fall	Nearly pure wood chips from 25–30 cm dia red oak tree felled by authors in fall of 1997; chips passed through a 2–3 cm dia screen.	0.06	748
23	Producer #3 wood, bark, & yard waste	Wood and bark blended with composted yard waste (leaves and grass clippings); shredded; collected on-site by authors from producer's yard piles; derived from various tree species; double ground	0.35	124
24	Producer #2 premium 'bark'	Predominately bark, but contained approx. 5% wood, collected by authors from producer's yard piles; shredded; derived from various tree species; double ground	0.34	132
25	Cedar	Stringy, wood and bark; finely shredded; purchased in bags from local retail outlets	0.27	172
26	Wood chips dyed black	Air-dried pure white oak wood chips (2–3 cm dia) dyed by authors from commercial, concentrated-powder dye	0.07	687
27	Wood chips dyed blue	Air-dried pure white oak wood chips (2–3 cm dia) dyed by authors from commercial, concentrated-liquid dye	0.07	687

[z]%N and C:N ratio of treatments 8, 9, 26, and 27 determined prior to dyeing and are the same as treatment 6, non-dyed white oak chips; dashes indicate no data.

leaves, and chipped wood that had been composted for 3–4 months. Spent mushroom substrate (SMS), consisting of steam-pasteurized horse and chicken manure, gypsum, and a proprietary nutrient supplement, was obtained immediately prior to use from a commercial mushroom house in southeastern Pennsylvania.

Four commonly used mulch-coloring products (black, blue, brown, and red) were obtained from dye manufacturers and used to dye white oak wood chips. Hue and color intensity were matched to commercially dyed products sold by the mulch industry.

In total, 27 different mulches were used in the study (Table 1).

Inoculum. Gleba of the artillery fungus were originally collected from the outside walls of a greenhouse on campus of The Pennsylvania State University, University Park, PA (3). The gleba had been plated onto oatmeal agar, one per dish, and an isolate selected based on abundant sporulation in the resulting culture (3). We utilized the same isolate of *S. stellatus* as we had used in previous experiments (2, 3), and inoculum consisted of new gleba removed from the Petri plate lids of pure subcultures of this isolate.

Field plots. Eighty-one field plots, consisting of 27 treatments in three blocks, were established in 1998 at The Russell E. Larson Agricultural Research Farm of The Pennsylvania State University, Rock Springs, PA. Each treatment plot was 0.7 m wide × 1 m long (2 ft × 3 ft) with a 0.7 m high back wall covered with white aluminum. Plywood walls, attached at right angles to the back wall and separating individual treatments, were 0.7 m × 0.7 m, and painted white. This structure created a total target area (back wall, two sides, three replications) per treatment of *ca*. 5 sq m (54 sq ft). Grass and weeds were removed from each plot, and mulch treatments applied to a depth of 12–13 cm (*ca*. 5 in) onto bare soil.

Each plot was inoculated with 10 gleba of the artillery fungus in July 1998, 10 gleba in September 1998, and four gleba in April 2000. Each mulch treatment was replicated three times in a randomized design and all plots were inoculated. During the summers of 1998 and 1999, all plots were watered during dry periods to aid initial colonization. During wet periods of these 2 years, and throughout 2000–2002, plots received only natural rainfall.

Data. Sporulation was recorded as the number of gleba attached to each target, comprised of the back wall and two sides of each field plot. Numbers of new gleba on each target were recorded in November 1999, April 2000, June 2001, October 2001, and June 2002, and numbers of accumulated gleba calculated. Mean number gleba accumulated as of the last collection date (June 26, 2002), were subjected to statistical analyses. A $\log_{10}$ transformation was used to normalize the data. Transformed data were subjected to Analysis of Variance (ANOVA) and significant differences ($P = 0.05$) among treatment means determined using Fisher's mean separation test (Minitab, Version 12.1, State College, PA). A simple correlation was conducted to test ($P = 0.05$) the relationship between the number of gleba and %N or C:N ratio since these two factors may affect fungal sporulation (3, 5). To illustrate a time trend, number gleba for the three mulches supporting the most sporulation were graphed over time.

Results and Discussion

Statistical results. The ANOVA, based on number of gleba accumulated by June 26, 2002, revealed that the level of sporulation differed significantly among treatments ($P \geq 0.001$). Fisher's mean separation test revealed that three mulches from the yard piles ('Producer #1 wood and bark mix', 'Producer #2 wood & bark mix', and 'Producer #3 wood, bark and yard waste mix') supported significantly ($P \geq 0.05$) more gleba than the other mulches. Analyses were conducted on means, but accumulated totals per target area are listed as these directly relate to the problem on house siding. There were 689–718 accumulated gleba on the target walls of the three yard pile mulches, and 10–333 gleba on the other mulches (Table 2). However, the data varied greatly, possibly related to the high degree of variability in microbe

Table 2. Accumulative number of gleba observed on the target walls from November 1999 to June 26, 2002. Each mulch treatment (3 replications) was inoculated with 10 gleba in July 1998 and September 1998, and 4 gleba in April 2000.

		Total gleba/date of data collection				
Treat. no.	Mulch description	Nov. 1999	April 2000	June 2001	Oct. 2001	June 2002
4	White pine bark, fall 1997	0	1	9	10	10
3	Red oak bark, fall 1997	0	0	13	23	24
17	White pine bark, spring 1998	0	0	14	19	27
21	100% spent mushroom substrate	2	2	16	42	43
19	Yellow-poplar wood, fall 1997	2	2	35	39	50
2	Yellow-poplar bark, fall 1997	2	2	11	48	51
26	Oak wood chips dyed black (2 reps only)	0	0	12	46	53
16	Yellow-poplar bark, spring 1998	0	0	24	47	63
1	White pine wood, spring 1998	1	1	11	62	66
11	Cypress	1	1	9	59	75
13	Pine bark mini-nuggets	8	8	67	97	104
6	White oak wood, spring 1998	2	2	32	93	108
8	Oak wood chips dyed brown	10	11	127	91	126
24	Producer #2 premium 'bark'	59	63	80	128	132
22	Red oak wood, fall 1997	8	8	27	119	134
5	White oak bark, spring 1998	4	6	51	139	150
9	Oak wood chips dyed red	3	3	67	135	159
18	Yellow-poplar wood, spring1998	6	7	74	153	177
27	Oak wood chips dyed blue	1	1	35	163	184
25	Cedar	7	7	96	193	202
12	Producer #2 'bark'	8	8	157	206	213
20	5% yard compost	20	25	181	202	238
14	White pine wood, fall 1997	1	1	30	202	260
10	5% sewage compost	32	41	162	235	333
15	Producer #2 wood & bark mix	46	54	443	660	689[z]
23	Producer #3 wood, bark, & yard waste	10	10	420	683	698[z]
7	Producer #1 wood & bark mix	7	9	455	665	718[z]

[z]Number of gleba significantly ($P < 0.05$) different from all other values in last column, but not among these 3 values, according to Fisher's mean separation test; all other comparisons are non-significant.

populations within mulch and compost. Many interactions between the artillery fungus and associated microbes, including fungi and bacteria that may be antagonistic to the artillery fungus (2), occur under field conditions. To facilitate discussing observed trends, the 27 treatments are grouped into nine general categories that had common characteristics: yard pile mixtures of bark and wood, mulches blended with 5% compost, cedar mulch, mulches purchased as 'bark' but containing considerable wood, dyed wood chips, non-dyed wood chips, cypress mulch, pure bark, and spent mushroom substrate.

Yard piles. 'Producer #2 wood & bark mix', 'Producer #3 wood, bark, & yard waste mix', and 'Producer #1 wood & bark mix' supported significantly more gleba than the remaining mulches (Fig. 1, Table 2). Target walls had accumulated 718, 689, and 698 gleba for these three mulches, respectively, by June 26, 2002, which corresponded to a density of *ca.* 13 gleba per sq ft. These results are similar to those from our previous study (3) in which we reported that two commercial mulches obtained from large piles, out of 18 treatments, supported the greatest amount of sporulation by the artillery fungus.

We collected these bulk mixtures from large, dark piles in mulch yards. The mixtures were mainly wood, with perhaps 5–10 percent bark, and were shredded. The shredded nature of these commercial mulches resulted in enhanced moisture-holding capacity, which favors the artillery fungus. Some of the mixtures also contained soil and debris from land-clearing operations. Although pure wood will support growth of many Basidiomycetes, a supplement of nutrients generally enhances sporulation (15, 16). A small supplement of bark and other debris apparently added a critical amount of N, vitamins, and/or minerals to the wood mulch that stimulated sporulation. Also, the large, dark piles of mulch had been composting (and were routinely turned to prevent over-heating and fires) from mid-summer to the next spring. The heat generated by this composting process kills many competing, non-thermophilic organisms, affording a vacant ecological niche that the ubiquitous artillery fungus can later exploit. It

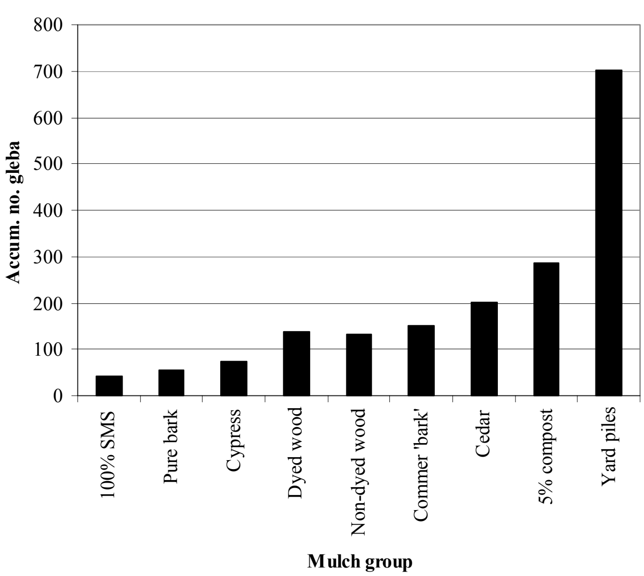

Fig. 1. Total accumulation of artillery fungus gleba for all 27 mulches, grouped into 9 categories that had common characteristics.

is possible that the artillery fungus can even grow on the cooler surface of the pile in between turnings.

5% compost. The two mulches containing waste amendments ('5% sewage compost' or '5% yard waste compost') supported fairly high levels of artillery fungus (Fig. 1, Table 2). These amendments most likely added nutrients that enhanced sporulation of the artillery fungus. Such blends should obviously be avoided, since they appear to stimulate artillery fungus colonization and sporulation.

Cedar and cypress. Cedar and cypress mulches are discussed together because both are considered generally resistant to decay (14, 18). We previously reported that cedar and cypress mulches inhibited colonization and sporulation by the artillery fungus in limited tests (3). Cypress supported less sporulation than cedar. However, within that study we only tested cypress in the field, where it did inhibit the artillery fungus (3). In that previous field study, cypress mulch also was slightly more resistant to the artillery fungus than was cedar (Fig. 1, Table 2). The artillery fungus appears to be slightly more sensitive to cypress anti-fungal chemicals than to those of cedar. In addition, our unpublished field observations indicated that cypress mulch might be more water repellent than cedar, further inhibiting the artillery fungus due to an unfavorable moisture regime.

Commercial 'bark'. The commercial mulches advertised as 'bark' (Fig. 1, Table 1), were not pure bark, but contained considerable wood. The pine bark mini-nuggets were purchased locally in plastic bags, and the other two bark products were shoveled from large, dark, wet mulch piles. As we noted previously (3), the artillery fungus usually grew and sporulated on the wood pieces, rather than on bark, within all of these mixtures. The lack of sporulation on the bark pieces may be related to their water repellent nature.

The mini-nuggets appeared to contain less wood than the products from the yard piles, but were much smaller than the large, dry pine bark nuggets that we had previously reported as being resistant to the artillery fungus (3). These mini-nuggets retained much more moisture than the larger pine bark nuggets and were more conducive to colonization.

Wood chips. Pure wood chips, whether dyed or non-dyed, tended to support more artillery fungus sporulation than did the pure bark products (Fig. 1, Table 2). Again, these were pure products that we prepared ourselves. The artillery fungus grew and sporulated better on pure wood than on pure bark, probably because the wood was less water repellant and tended to absorb moisture readily. The 'White pine wood, spring' and 'Yellow-poplar wood, fall' had the least amount of sporulation among all the chip products (Fig. 1, Table 2). These two mulches also had low %N (Table 1). Although the artillery fungus can grow well on wood products, it may require some critical level of N or other nutrients for optimum sporulation, as do other fungi (7).

In related studies, we noted that the artillery fungus colonized dyed wood chips more slowly than non-dyed wood chips. Akina (1) tested the fungitoxic nature of many dyes, and concluded that the chemical nature of the dyes was unrelated to reduced sporulation. We previously noted that dyed wood chips were initially very water repellent (3). However, as dyed chips weathered in the field due to sunlight and rain-

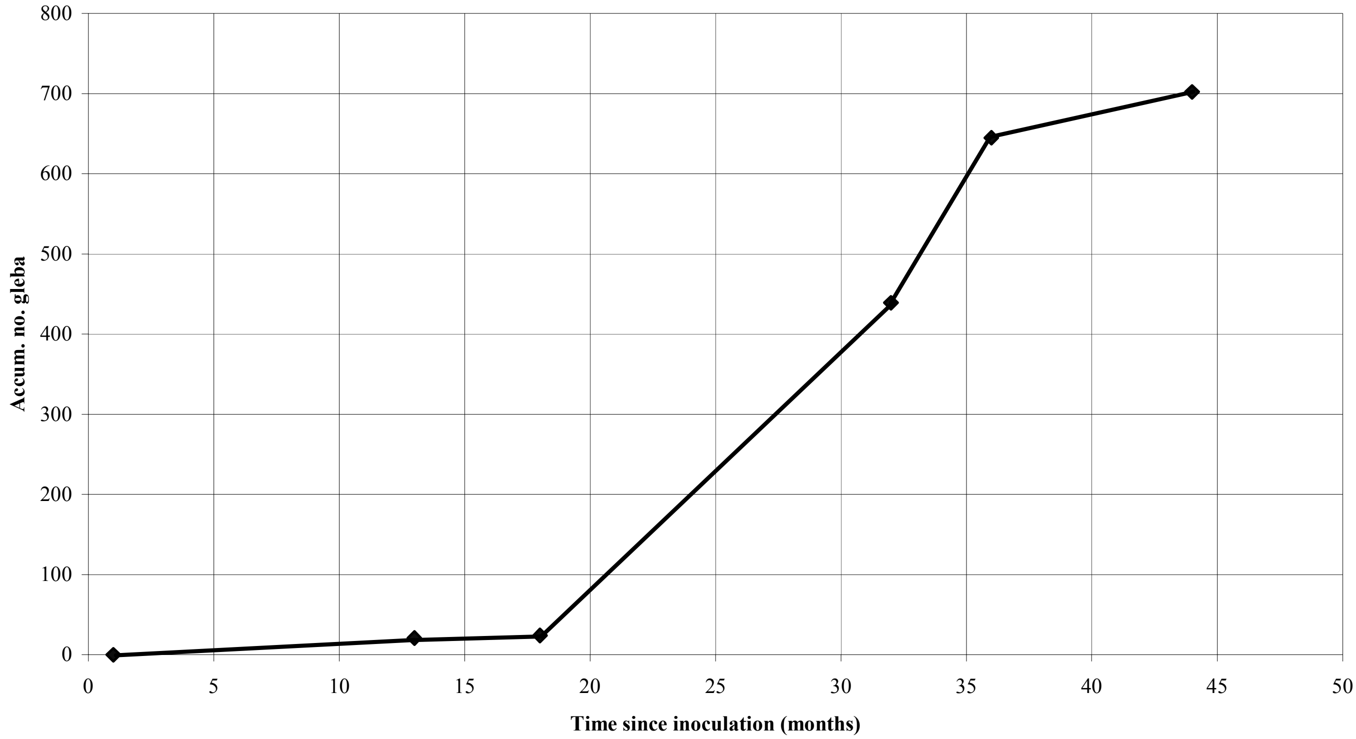

Fig. 2. Total accumulation of gleba over time for the 3 mulches (treatments 7, 15, 23 in Tables 1, 2) that supported greatest sporulation of the artillery fungus.

fall, the dye was broken down or leached from the wood chips, and the artillery fungus colonized and sporulated on the mulch. Therefore, we ascribe initial reduction in sporulation on dyed chips mainly to water repellency. An artificial spray that will increase the water repellent nature of the mulch may inhibit the artillery fungus in a similar manner.

Pure bark. Mulches comprised of pure bark, that we prepared ourselves, generally supported low levels of artillery fungus sporulation (Fig. 1, Table 2). Bark mulches made from white pine, yellow-poplar (tuliptree), and northern red oak generally remained in large, hard, dry pieces and supported least sporulation among the bark mulches. These findings support our observations around homes and previous findings (3) that bark products such as large, hard 'nuggets' support low populations of the artillery fungus. Again, this inhibition is likely due to the water repellent nature of these products. Mulch made from white oak bark supported greater levels of the artillery fungus (Table 2), as compared to the other bark products, probably because the white oak bark consisted of small, soft flakes. The small flakes absorbed water and remained wet, likely favoring growth and sporulation of the artillery fungus. Similarly, we previously observed that wet and decomposing red oak 'bark' (containing some wood) (3) and the soft, flakes of eastern hemlock bark supported considerable artillery fungus. Thus, the resistant nature of the large, hard bark pieces or nuggets is more likely due to water repellency, rather than other features such as the fungal toxicity of bark suberin (12). If used, the large bark nuggets should be placed on landscape cloth or black plastic to maintain soil moisture and reduce weeds. However, even pure bark mulch will eventually support the artillery fungus over a long period of time (*i.e.*, 3–4 years) unless it remains hard and dry.

100% spent mushroom substrate. The '100% spent mushroom substrate' (SMS) supported very little artillery fungus sporulation (Fig. 1, Table 2). This result is important, since in Pennsylvania alone, nearly 700,000 cubic yards of SMS is produced each year. SMS is generally viewed as an undesirable byproduct within the mushroom industry. A significant use for this substrate would be to utilize it as landscape mulch. This use would solve a disposal problem for the mushroom industry, open markets for use of the SMS as a salable product to the landscape industry, and perhaps decrease the incidence of the artillery fungus.

Spent mushroom compost contains in excess of 1% N. Interestingly, we previously reported that a wood and bark mulch composted with sewage sludge inhibited most sporulation by the artillery fungus. That mulch contained *ca.* 1.2% N. Also, evidence reported to the authors suggests that the artillery fungus fails to sporulate on mulch made from a mixture of poultry manure and sawdust. This mulch would also contain a high % N, but may also contain N in a form (e.g., ammonia) that inhibits the artillery fungus, or may contain populations of microorganisms that suppress the artillery fungus (2).

% N and C:N ratio. Although extremely low or extremely high levels of N may inhibit sporulation by the artillery fungus, numbers of gleba were not significantly ($P = 0.05$) correlated with % N or C:N ratio of the mulch (data not shown). Apparently, % N and C:N ratio by themselves are poor indicators of potential susceptibility of mulch to colonization or sporulation by artillery fungus (3).

Time trends. By November of 1999 (12 months after initial inoculation), at least one gleba per target was observed for 22 of the 27 mulches (Table 2). Sporulation increased slightly by April 2000 (17 months) and then increased rapidly through June 2001 (31 months). Rapid sporulation continued through October 2001 (35 months) until the experiment was terminated June 26, 2002 (43 months). These findings are illustrated graphically for the three mulches (average of treatments 7, 15, 23) that supported the greatest sporulation (Fig. 2). Results were somewhat similar to our previous findings (3), in that we reported that nearly 3 years were required for significant levels of artillery fungus sporulation to occur in the field plots. In the Northeast, the artillery fungus sporulates outside in the cool, moist spring, and then again in the fall. It is greatly inhibited by hot, dry weather during the summer. In years with a mid-summer dry period, the artillery fungus may sporulate in the field for only two brief bursts per year. However, our laboratory and growth room work (1, 3) shows that the fungus can readily grow on mulch and sporulate year-round, if moderate temperature and adequate moisture are provided, until critical elements in the substrate are exhausted.

We often receive homeowner accounts wherein artillery fungus problems arise the year following application of new mulch. The artillery fungus commonly occurs on dead trees, dead branches, rotting wood, etc. If this material is used for mulch, the artillery fungus may be already in the mulch when it arrives at a job site, and may grow rapidly during cool moist conditions. Or gleba may already be present at the site on old mulch, previously infested plant leaves, or decaying organic matter such as dung, decaying leaves and grass, compost piles, etc. These existing gleba may immediately infest new applications of mulch. In some cases, gleba also may be transported for very short distances via wind from adjacent infested mulches or decaying organic matter. People can also spread the fungus in various ways. Some homeowners make the mistake of sanding, scraping, or otherwise removing the gleba from the sides of their houses, and letting the gleba fall onto the mulch. Such gleba are dormant, but very much alive and re-inoculate the mulch. Also, artillery fungus growth in new mulch may be rapid if the new mulch had been composted at high temperatures, and potentially competing organisms destroyed. Nature, and the artillery fungus, abhors a vacuum.

In summary, mulches made of large, hard, dry pieces of pure bark, such as large pine bark nuggets (3), generally fail to support as much artillery fungus as did mulches made of shredded wood or shredded wood-bark mixtures. Likewise, cypress mulch and 100% spent mushroom substrate prevented colonization and sporulation by the artillery fungus. Also, Akina (1) reported that 'licorice root' mulch, as sold in southeastern Pennsylvania, inhibited the artillery fungus in laboratory studies. In addition, the authors have observed that that the artillery fungus may not grow well on fresh 'pine straw' mulch.

Many current markets demand shredded mulch rather than nuggets. The finer nature of shredded mulch ensures that it will retain greater moisture levels, which in turn favor colonization and sporulation by the artillery fungus. The initial water repellency of some dyed shredded mulches may delay growth and sporulation of the artillery fungus.

Spent mushroom substrate, pine bark nuggets, cypress mulch, and licorice root all deserve further study and consideration as mulches that may inhibit the artillery fungus. However, one must remember that all mulches studied eventually supported some sporulation of the artillery fungus. Almost all organic landscape mulches lose their resistance to colonization by the artillery fungus over several years. Homeowners have reported that applying a fresh layer of mulch each year will minimize the artillery fungus, but we have not tested this practice. Even the more tolerant mulches should be replaced on a regular basis, as they begin to break down. In critical situations, the best control for the artillery fungus problem can be achieved by replacing organic landscape mulch with black plastic overlain with stone.

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