12-1988

Allelopathic effect of landscape mulches on the germination of weed seeds and growth of ornamental plants

Karen Kay Stein

To the Graduate Council:

I am submitting herewith a thesis written by Karen Kay Stein entitled "Allelopathic effect of landscape mulches on the germination of weed seeds and growth of ornamental plants." I have examined the final electronic copy of this thesis for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Science, with a major in Landscape Architecture.

Donald B. Williams, Major Professor

We have read this thesis and recommend its acceptance:

John W. Day, Hendrik van de Werken

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John W. Day

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ALLELOPATHIC EFFECT OF LANDSCAPE MULCHES ON THE GERMINATION OF WEED SEEDS AND GROWTH OF ORNAMENTAL PLANTS

A Thesis

Presented for the

Master of Science

Degree

The University of Tennessee, Knoxville

Karen Kay Stein

December 1988

ACKNOWLEDGMENTS

The author wishes to express her gratitude to Dr. Donald B. Williams, Professor, Department of Ornamental Horticulture and Landscape Design for being an excellent mentor and friend. Him and his wife Sue for their thoughtfulness and generosity which was well appreciated.

The author expresses her appreciation to Dr. Hendrik van de Werken, Professor, and Dr. John W. Day, Associate Professor, Department of Ornamental Horticulture and Landscape Design, for their guidance, serving on her committee, and review of the manuscript. She would personally like to thank Dr. Hendrik van de Werken for sharing his humor and words of wisdom, and Dr. John W. Day for his interest and concern.

The author is also thankful for the financial support provided by the College of Agriculture and Department of Ornamental Horticulture and Landscape Design.

The author also expresses her appreciation to Dr. James R. Jackson, Professor, Department of Biology, Missouri Southern State College, for preparing her for graduate school and his unending encouragement. His father, Guy R. Jackson for instilling his wisdom and optimism.

The author wishes to thank the graduate students, other faculty members, and staff of the Department of

Ornamental Horticulture and Landscape Design, especially Dr. Gary L. McDaniel, Professor, for all his help and advice, Dr. Glenn D. Crater, Head, for his energetic personality, the secetaries for their valuable tasks and pleasant personalities, the greenhouse and nursery managers, the lab technicians and the plot barn crew.

Finally, the author wishes to extend her appreciation to her family and Missy for their unlimited encouragement and support.

ABSTRACT

Weed seed germination and ornamental plant growth response to selected mulch materials (33 types) were tested in the field and greenhouse at the University of Tennessee, Knoxville in 1987 and 1988. Two field (experiment 1 and 2) and two greenhouse (experiment 3 and 4) studies were set up using morningglory, large crabgrass, and pigweed seeds. Ornamental plants tested in experiment 1 were Lagerstroemia indica L. (common crapemyrtle), Cotoneaster dammeri C.K. Schneid (bearberry cotoneaster), Salix triandra L. 'Brilliant' (willow), Acer rubrum L. (red maple), Tagetes sp. (marigold), and Helianthus sp. (sunflower). Ornamental plants tested in experiment 2 were Ilex x Meserveae S.Y. Hu. 'Blue Girl' (holly), Euonymus alatus (Thunb.) Siebold. 'Compactus' (euonymus), Cornus florida L. (flowering dogwood), and Cotoneaster congestus Bak. (pyrenees cotoneaster).

In the greenhouse experiments only the three weed seeds were tested. For experiment 3, a layer of mulch was spread over the seeds which were on mined quartz sand in four-inch round pots. For experiment 4, leachate derived from the mulch materials was poured over the weed seeds which were also on sand in pots. Soluble salt and pH levels of the leachate were obtained in experiment 4.

The results of all experiments were analyzed with ANOVA and the means separated according to Duncan`s multiple range test at the 5% level of probability and significance was compared to the control(s).

In experiment 1, the most significant mulches that inhibited germination of the weed seeds were black walnut leaves against morningglory, barley straw against large crabgrass, and rye straw against pigweed. Growth of the red maple test plant species was significantly inhibited by wheat straw.

In experiment 2, the most significant mulches that inhibited germination of the weed seeds were eastern hemlock foliage and wheat straw against morningglory, and sugar maple sawdust and black walnut wood shavings against pigweed. Euonymus growth was significantly inhibited by sugar maple sawdust, and holly growth was significantly enhanced by eastern red cedar wood chips.

In experiment 3, the most significant mulches that inhibited germination of the weed seeds were alfalfa against morningglory, red maple leaves against large crabgrass, and eastern red cedar wood chips against pigweed.

In experiment 4, the most significant mulch leachate that inhibited germination of the weed seeds were red maple leaves against morningglory and pigweed, and eastern hemlock foliage against large crabgrass. The greatest correlation between soluble salt readings and germination occurred with morningglory (r = -.58). The greatest correlation between pH readings and germination occurred with large crabgrass (r = .47).

Due to the lack of supporting research in this topic further experiments should be done to provide definite conclusions. This research could provide valuable information and guidelines for additional research.

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I. INTRODUCTION

The control of weeds in urban landscapes is of major concern. The use of herbicides has increased dramatically and the dangerous side effects of these chemical systems cause concern for environmental pollution. Therefore the utilization of natural controls, such as the release of herbicidal agents from organic mulches would be appealing. The safety and convenience of applying this natural means of weed control is important. Einert and others (1975) evaluated the herbicidal effects of various mulches in home gardens by determining the amount of time reguired for weeding. None of the mulches completely controlled weeds, but less weeding was necessary when pine bark was used. If organic mulches were selected based on their ability to control weeds, then more kinds with herbicidal activity might be known today.

This research project was designed to test various plant materials as mulches for weed control. The selection of plant materials was based on the phenomenon of allelopathy. According to Mandava (1985) the word allelopathy was derived from two Greek root words:

allelon - of each other
and   = the injurious effect of one
pathos - to suffer   upon another

Rice (1974) states that Molisch coined the term allelopathy in 1937 to refer to biochemical interactions (detrimental and beneficial) between all types of plants including microorganisms. Rietveld (1975) states that Whittaker defined allelochemicals as "chemicals released from higher plants (directly or by way of decay processes) that inhibit the germination, growth, or occurrence of other plants." However, Rice (1974) used the term as "any direct or indirect harmful effect by one plant (including microorganism) on another through the production of chemical compounds (allelochemicals) that escape into the environment." Therefore no matter how one perceives allelopathy it is still separate from natural plant competition. Allelopathy is caused by the release of chemicals into the environment, not competition for water, light, and nutrients between plant species.

No research publication on the allelopathic effect of mulches in an urban landscape was found. Therefore the objectives of this research project were: (1) to determine the allelopathic effect of landscape mulches on germination of weed seeds and (2) to determine the allelopathic effect on the growth of ornamental plants. The goal is to find mulches that not only control weeds by the release of allelochemicals but are not harmful to the ornamental plants around which the mulch is spread.

II. LITERATURE REVIEW

The effects of allelochemicals were known before 285 B.C. by Theophrastus (Rice 1983) who observed that chick-pea does not reinvigorate the ground as other legumes do but exhausts it instead and destroys weeds. Pliny (Rice 1983) wrote a series of books in the first century A.D. and found that chick-pea, barley, oats, bitter vetch, flax, and poppies scorched cornland. He also stated that walnut trees caused headaches in man and injury to anything planted in their vicinity and pine trees killed grass. He adivised that the best way to kill bracken fern was to knock off the stalk with a stick when it is budding, thus allowing its juice to drain down kill the roots. In the 17th century Kumazawa (Rice 1983) documented that rain and dew washing the leaves of red pine was harmful to crops growing under them.

During the 1800's many more observations were reported. However, there were no controlled experiments until this century. In the early 1900's Schriener and Reed (Rice 1983) demonstrated that roots of seedling crop plants such as wheat and oats exude chemical compounds that effect the roots of seedlings of the same species. Pickering (Rice 1983) demonstrated that leachate from certain species of grasses will inhibit the growth of apple seedlings. By 1925 Massey (Rice 1983) had done a careful study showing the wilting and death effect on alfalfa and tomato plants when their roots are in close contact with walnut tree roots. In 1928 Davis (Rice 1983) identified the toxic substance in walnut to be juglone.

By 1940 Bode (Rice 1983) reported that the growth of several plant species within one meter of wormwood plants had been inhibited by foliar excretions. Benedict (Rice 1983) observed that smooth brome pastures were substantially thinned after 2 or 3 years. He performed several experiments first using oven dried roots of the grass species and incorporated them into soil containing seeds of the species and found that there was a significant reduction in dry weight of the seedlings. Secondly he added water leachate from an old culture of smooth brome to seedlings and obtained similar results.

From historical information and more current research different kinds of allelochemicals and their method of release into the environment have been identified. There are two primary routes of release but several methods within each one (Rietveld 1975):

A. To soil from above ground plant parts
1. Volatilization
2. Rain (dew) washings from the plant surfaces
3. Leachate from fresh litter
4. During decomposition of litter

B. Within the soil
1. Root exudation
2. Leachate from living and dead roots
3. Decomposition of roots and incorporated residues

Many individual allelochemicals have been identified and arbitrarily classified into separate families (Putnam 1985):

- Toxic gases
- Organic acids and aldehydes
- Aromatic acids
- Simple unsaturated lactones
- Coumarins
- Quinones
- Flavonoids
- Tannins
- Alkaloids
- Terpenoids and steroids
- Miscellaneous and unknown

The production of these chemicals varies depending upon the environment and in particular the response to stress. Research has shown that ultra violet light greatly enhances allelochemical production. Therefore, plants grown in the greenhouse may only produce a limited amount of chemicals. Also nutrient deficiencies may either enhance or decrease the production of allelochemicals depending upon the species. The type and age of plant tissue is very important since the allelochemicals are not distributed uniformly in the plant. Different species and individuals within species produce these chemicals in different amounts. Several parameters by which these allelochemicals may exert their inhibitory actions upon are (Rice 1974):

- Cell division and elongation
- Growth hormones
- Mineral uptake
- Photosynthesis and respiration
- Stomatal opening
- Protein synthesis and changes in lipid and organic acid metabolism

Allelopathy in Agriculture

Even though there is evidence for the action of allelochemicals it is not always easy to determine that an allelopathic response is occurring. Considerable research on allelopathy in agriculture has been reported and is an on going topic. Most of the research has been accomplished through the use of extracts from plants and field studies.

Crop - Crop Response

Miller (1983) conducted several field experiments and determined that alfalfa did not grow very well under continuous cropping as compared to rotating with soybeans and corn. In general there were no differences between culitivars in response to allelochemicals.

According to Rice (1974) Borner experimented with cold water extracts of barley, rye, wheat, and oats and reported that they inhibited root growth of wheat. Grant and Sallans found that grass top extracts from timothy, orchard grass and reed canary grass reduced the germination of these grass species significantly. Timothy, reed canary grass, and orchard grass top extracts also reduced germination of ladino clover. From the legume extracts of alfalfa, red clover, ladino clover, and birdsfoot trefoil, alfalfa root extracts severely reduced germination of all four grass species and red clover. Ladino clover top extracts reduced the germination of all species except timothy and birdsfoot trefoil.

Crop - Weed Response

Peters and Zam (1981) tested for allelopathic effects of leaf extracts from tall fescue genotypes against birdsfoot trefoil and red clover. These legumes are frequently grown with tall fescue in pasture mixes. It was found that only certain genotypes inhibited germination and growth of both legumes. Elmore (1985) found that johnsongrass and purple nutsedge rhizome extracts inhibited growth development of barley, mustard, wheat, and cotton.

Crop Residue - Weed Response

Two diferent studies were done on crop residues and their effect on weed densities (Tables 1 and 2).

Allelopathy in Forestry

Tree - Understory Response

Hook and Stubbs (1967) observed that in a mixed bottomland hardwood site the gwth of the understory was greatly retarded under a high percentage of three oak species, particularly cherrybark, swamp chestnut and shumard. The retardation was more pronounced and prevalent in the lower wet areas. They suggested that root exudates

Table 1. Influence of tillage and crop residues on weed densities.(Putnam and others 1983)

Tillage	Residues	Weeds/m^2
conventional	none	124.3
none	none	51.0
none	rye	4.3
none	wheat	3.2
none	barley	8.2

Table 2. Effect of tillage and rye residues on weed density. (Shilling and others 1985)

Treatments	Redroot Pigweed plants/ 2.2m^2	Common Lambsquarters plants/ 2.2m^2	Common Ragweed plants/ 2.2m^2
remove mulch, no-till	8	25	21
remove mulch, till	4	132	236
cut-mulch, no-till	2	7	17
remove mulch, till, replace mulch	3	120	186
glyphosate, no-till	2	5	9
paraquat, no-till	1	5	16
no rye, till	26	140	140
no-rye, no-till	21	41	15

or crown leachates might be causing the inhibition of the understory. DeBell (1971) investigated this phenomenon further and found that in greenhouse studies sweetgum and cherrybark oak germination and seedling growth were both reduced in soils collected from beneath cherrybark oak. Also he found that cold water extract of fresh cherrybark oak leaves inhibits the growth of sweetgum seedlings and not cherrybark oak seedlings.

According to Rice (1974) Del Moral and Muller investigated the occurrence of bare areas beneath the tree Eucalyptus globulus. They noticed that even as a landscape plant when the litter was not allowed to accumulate herbaceous species were suppressed. After a series of experiments and knowing that fog is very common in this area, they concluded that the fog drip was responsible for the lack of herbaceous species.

Litter - Understory Response

Al-Naib and Rice (1971) observed reduced growth of herbaceous plants beneath the canopy of sycamore trees. They determined that decaying leaves, leaf leachate, and soil collected from beneath the trees inhibited germination and seedling growth of various species. Consequently Lodhi (1975) came to the same conclusion for the lack of herbaceous species beneath hackberry trees in a forest community. Lodhi (1976) also observed a noticeable difference in the pattern of herbaceous growth under elm, sycamore, hackberry, red oak, and white oak trees. The herbaceous growth under the latter four species appeared to be reduced compared to under the elm trees. Decaying leaves, leaf leachate, and soil collected from under the four trees was tested for possible allelopathic effects. The three test media from all four species significantly reduced seed germination, radicle growth, and seedling growth of selected herbaceous species. Growth inhibitors, mainly phenolics, were isolated and identified from the leaves and soil of the four test species.

Lodhi and Killingbeck (1982) reported that decaying needles, needle leachate, bark extracts, and field soil from a Pinus ponderosa community significantly reduced germination and radicle growth of Andropogon gerardii and Andropogon scoparius.

Ward and McCormick (1982) investigated the problem of poor natural regeneration of eastern hemlock, a commercial timber species. Allelopathy was suggested as a possible cause. Aqueous extracts of hemlock litter caused a 74% reduction in germination and 100% mortality in 6 day old seedlings. However, the extracts had no effect on hemlock seedlings older than two weeks, which suggests that allelopathy specifically occurs in the initial stages of reproduction.

General

Fisher (1980) has compiled a list of some allelopathic plants based on references from recent North American forest and ecological literature. The list includes woody and herbaceous plants, the class of chemical produced, and an example of the species affected by the chemical.

Allelopathy in Horticulture

Greenhouse Crops

According to Rice (1974) Kozel and Tukey found that Chrysanthemum morifolium produced a toxic chemical that leaches from the leaves and inhibits the growth of chrysanthemum. Tukey stated later that chrysanthemums should not be grown in the same soil for several years. Also greenhouse supervisors have suggested that many crucifers poison soils of other plants and themselves.

Woody Ornamentals

Oleksevich (1970) reported that barberry, horse chestnut, rose, lilac, viburnum, fir, and mockorange cause soil toxicity and are capable of inhibiting the growth of neighboring plants.

According Whitcomb (1972) Kentucky bluegrass was found to be the most sensitive of several grasses to tree root effects from silver maple and honeylocust not only because of nutrient competition but possibly due to an inhibitor released into the soil. Red fescue was not effected by any of the experimental conditions. Perennial ryegrass and roughstalk bluegrass under shade did not respond differently to the presence or no presence of a tree, until the tree top began to actively grow. Whitcomb concluded that tree roots reduced the growth and vigor of grasses even when water and nutrients were maintained at optimum levels suggesting that allelopathic effects may be involved.

Nielson and Wakefield (1978) studied the competitive effects of a well established turfgrass on the growth of newly planted ornamental shrubs. Four shrub species, forsythia, azalea, Japanese barberry, and yew were planted in a two year stand of Kentucky bluegrass, red fescue, and colonial bentgrass. Nitrogen fertilizer and irrigation were maintained at different levels. After two years, it was determined that the growth of all species were significantly suppressed, not due to differences in soil moisture, temperature, and competition for nitrogen, but other environmental and/or soil factors.

Fales and Wakefield (1981) conducted research using flowering dogwood and forsythia planted in a three year mixed sod containing Kentucky bluegrass and red fescue with different sized areas of turf-free space around the plants. Different fertilizer and irrigation schemes were used. Reduced growth of both woody species was evident and nitrogen competition was indicated. In a bioassay experiment, root leachates of perennial ryegrass, red fescue, and Kentucky bluegrass suppressed top and root growth when applied to rooted forsythia cuttings. It was concluded that turfgrasses release allelochemicals as well as directly compete for nitrogen causing the suppression of woody plants.

A similar experiment was done by Whitcomb (1981) which involved dwarf Burford holly, hetzi Chinese juniper, Japanese black pine, and golden vicary privet planted in an established sod of U-3 bermudagrass with different sized areas of turf-free space around the plants. After two growing seasons it was evident that the plants with no turf-free space were much smaller than those that were grown with turf-free space. The possibility that allelopathy may be involved was suggested.

Nut Production

Black walnut is the species most commonly associated with allelopathy. Rietveld (1983) experimented with juglone (the toxic chemical from black walnut trees) to determine the sensitivity of 16 species, including herbaceous and woody species, considered for co-crops, nurse crops, and cover crops in black walnut plantations. Seed germination and radicle elongation were less affected than shoot elongation and dry weight accumulation. Although all species were sensitive to juglone, amur honeysuckle, sericea lespedeza, crimson clover, European black alder, and autumn olive were affected the greatest.

III. MATERIALS AND METHODS

Experimentation occurred in the nursery field research area and nursery greenhouse at the University of Tennessee, Knoxville. All experiments were set up according to the randomized complete block design and the control treatments consisted of pea gravel (inert) and/or no mulch. Mulch treatments consisted of wood products, straw, foliage from trees, and chopped herbaceous plants. It was important to test a species specific plant material in order pin point the source of allelochemicals. Also the variety of mulches available commercially is not very broad so additional plant materials were collected. Fresh bark and sawdust were collected from two area sawmills as the tree was being milled. Straw mulches were collected from the University farm and the tree foliage and herbaceous plants were collected wherever they could be found on University property. All mulches were stored in large plastic bags and labeled with a number and name. The numbers were then used for randomizing the mulches for experimentation. Straw, foliage, and herbaceous plants were air dried on greenhouse benches with a lathing top or hung from a ten foot high chainlink fence before storing in plastic bags. The plant materials were collected two months prior to the installation of the experiments.

Three types of weed seeds were purchased from the

Azlin Seed Service of Leland, Mississippi and tested for inhibition of germination by allelochemicals released from the mulches in all experiments. These were morningglory, large crabgrass, and pigweed.

Field Studies (Experiments 1 and 2)

Wood frames were built for defining the plots. A frame consisted of two 2.5 x 10 x 305 cm boards for the sides with five cross pieces 50 cm long to form four plots/frame. Thus each plot was 50 cm x 70 cm or 3500 cm^2. The frames were arranged in rows (replications) on the field site that had been tilled and raked smooth. The field site consisted of natural silt loam soil containing inherent weed seeds. There were approximately 90 cm between each replication to provide space for a walkway to make the plots accessible for collecting data. Six ornamental plants were planted in each plot approximately 20 cm from each other and 15 cm from the edge of the frame.

Experiment 1

The main purpose of this experiment was to provide preliminary information to establish guidelines for following experiments. Twenty types of mulch materials (Table 3) of wood products and straw were replicated four

Table 3. The 20 mulch treatments replicated in the 1987 summer field experiment, experiment 1.

Wood Products	Miscellaneous
Red Oak Sawdust	Black Walnut Leaves
Red Oak Bark	Wheat Straw
Eastern Red Cedar Wood Chips	Barley Straw
Pine Bark	Rye Straw
Pine Sawdust	No Mulch
Yellow Poplar Bark	Pea Gravel (control)
Yellow Poplar Sawdust	
White Oak Bark	
White Oak Sawdust	
Beech Bark	
Beech Sawdust	
Sugar Maple Bark	
Sugar Maple Sawdust	
Hickory Bark	

times. An additional row of 20 (Table 4) plant materials (foliage from trees and chopped herbaceous plants) were screened for possible allelopathic activity.

Four of the test plants were woody ornamental seedlings, Cotoneaster dammeri (bearberry cotoneaster), Salix triandra 'Brilliant' (willow), Lagerstroemia indica (common crapemyrtle), and Acer rubrum (red maple) selected from the University nursery. The other two test plants were herbaceous annuals, Tagetes sp. (marigold) and Helianthus sp. (sunflower) purchased as seed packets from a local garden center. The marigold seeds were sown in a seed flat and put under mist on May 12, 1987. The seedlings were transplanted on May 28 into bedding plant trays and remained in the greenhouse until planting time. The sunflower seeds were not sown into flats but were directly planted into the plots at planting time.

The weed seeds were weighed and counted to find out how many morningglory seeds are in 5 grams, crabgrass seeds in .5 grams, and pigweed seeds in .2 grams. Then the number of seeds needed for the experiment was based on the area of the field site. The goal was to have a morningglory seed every 50 cm^2, a crabgrass and pigweed seed every 10 cm^2.

Installation began on July 17, 1987 with the laying down of the frames to form the replications. The test plants were then planted in the plots.

Table 4. The 20 mulch treatments screened in the 1987 summer field experiment, experiment 1.

Foliage	Plant
Black Willow	Kudzu
Smooth Sumac	Common Ragweed
Black Cherry	Pokeweed
Eastern Red Cedar	Oat Straw
Red Maple	Yellow Nutsedge (+ roots)
Sassafras	Pigweed (+ roots)
Sugar Maple	Canada Thistle
American Sycamore	Crownvetch (+ flowers)
Bald Cypress	Purslane (+ roots)
	Johnsongrass
	Johnsongrass (roots only)

Five sunflower seeds were planted together/plot to be sure that one would germinate and grow. If more than one germinated the extras were discarded. The other 5 test plants were pruned to a height of approximately 8 cm and one stem before planting. The weed seeds were sown on July 18 with an Ortho Whirlybird spreader by walking back and forth along the walkways. On July 20 the mulches were spread in the plots from a wood box with a volume of 8793 cm^3, which is the equivalent of 2.5 cm thick layer of mulch/plot. Due to the bulky nature of the bark mulches one and a half boxes/plot were used instead of one box full. All straw mulches were spread out by filling the plot to the top of the frame. Rainfall was recorded (Table 5) and sprinklers were used between rainfalls to water plots. Due to the the variablity of the sprinkler, measuring devices were placed about the field site and the average amount of water was determined.

Germination count was recorded for only the three weeds sown. The three kinds of seeds that were sown did not occur naturally on the field site. All weeds were removed from the plots as seedlings including the ones that had been sown, after the count was recorded. Recording of germination started on July 24 and ended on August 25.

Fresh weight of the test plants were determined by cutting the plants off at the ground surface, placed in a

Table 5. Watering schedule for the 1987 summer field experiment, experiment 1.

Date	Inches of water
7/18	1.0
7/20	1.0
7/22	1.0
7/23	1.0
7/24	0.5
7/27	1.0
7/29	0.8
8/02	1.0
8/03	0.2 (rain)
8/06	2.7 (rain)
8/17	1.0 (rain)
Total	11.2

plastic bag, and carried inside to an electronic digital scale to be weighed. Fresh weights were recorded on the following dates in 1987:

Marigold and Sunflower	-	8/24
'Brilliant' Willow	-	9/28
Common Crapemyrtle	-	9/29
Bearberry Cotoneaster	-	10/01

Experiment 2

This experiment consisted mainly of treatments found significant in the preliminary studies plus additional plant materials from the literature review. The experimental design was the same as for experiment 1 except 24 mulches (Table 6) were replicated six times.

The wood frames were placed on the field site on November 27, 1987 and ornamental plants were planted in the plots. They were <u>Ilex</u> x <u>Meserveae</u> 'Blue Girl' (holly), <u>Euonymus alatus</u> 'Compactus' (winged euonymus), <u>Cornus florida</u> (flowering dogwood), <u>Cotoneaster congestus</u> (pyrenees cotoneaster), <u>Koelreuteria paniculata</u> (golden-rain tree), and <u>Helianthus</u> sp. (sunflower seeds).

Weed seeds were counted instead of weighed for each plot and stored in small zip-lock bags:

Morningglory	100	seeds/plot
Large Crabgrass	165	seeds/plot
Pigweed	300	seeds/plot

The plants were planted on November 27 and 28, 1987. On November 30 the weed seeds were scattered into each plot.

Table 6. The 24 mulch treatments replicated in the 1987 - 1988 overwintering experiment, experiment 2.

Wood Products	Foliage	Miscellaneous
Red Oak Sawdust	Black Walnut	Wheat Straw
Red Oak Bark	Red Maple	Oat Straw
Eastern Red Cedar Wood Chips	Black Cherry	Alfalfa
White Oak Bark	Eastern Red Cedar	Pokeweed
White Oak Sawdust	Eastern Hemlock	Pigweed
Sugar Maple Sawdust	Sassafras	Johnsongrass
Black Walnut Wood Shavings	Hackberry	No Mulch
	White Pine Old Needles	Pea Gravel(control)
	White Pine Fresh Needles	

The mulch materials were spread over the seeds in the same manner as before except bulky materials including leaves and straw were cut into smaller pieces so that one box full was used for each plot. The natural rainfall was the only source of irrigation. (Table 7).

On May 5, 1988 the first set of data were collected for the number of weeds that had germinated and developed into seedlings. Additional recordings were taken on June 3 and 24. Fresh weights were recorded on the following dates in 1988:

'Compactus' Euonymus	-	8/01
Flowering Dogwood	-	8/02
'Blue Girl' Holly	-	8/02
Bearberry Cotoneaster	-	8/18

Greenhouse Studies (Experiments 3 and 4)

To complement experiment 2, greenhouse experiments 3 and 4 were set up in December so that the growing conditions could be controlled to reduce the inherent variability outside. The experiments ran simultaneously for approximately one month. Both experiments were set up according to the randomized complete block design and replicated five times with 20 (Table 8) of the 24 mulch treatments tested in experiment 2, excluding pokeweed, pigweed, oat straw, and sugar maple sawdust. Both experiments required four-inch round pots filled with mined

Table 7. The record of rainfall for the 1987 1988 overwintering experiment, experiment 2.

Rainfall	
Date	Inches
12/3	.1
12/15	1.0
12/17 - 1/4	2.0
1/6	1.0
1/19	2.5
2/3	2.5
2/15	1.0
3/3	.5
3/10	2.0
4/6	2.0
4/18	1.0
4/22	1.0
5/4	1.0
5/10	.5
6/8	.5
6/20	1.0
7/13	2.0
7/21-23	1.5
8/3	.3
Total	23.4

Table 8. The 20 mulch treatments replicated in the greenhouse experiments, experiment 3 and 4.

Wood Products	Foliage	Miscellaneous
Red Oak Sawdust	Black Walnut	Wheat Straw
Red Oak Bark	Red Maple	Alfalfa
Eastern Red Cedar Wood Chips	Black Cherry	Johnsongrass
White Oak Bark	Eastern Red Cedar	No Mulch
White Oak Sawdust	Eastern Hemlock	Pea Gravel(control)
Black Walnut Wood Shavings	Sassafras	
	Hackberry	
	White Pine Old Needles	
	White Pine Fresh Needles	

quartz sand. Ornamental plants were not tested. The seeds were counted and stored in zip-lock bags:

Morningglory	20 seeds/pot
Large Crabgrass	50 seeds/pot
Pigweed	80 seeds/pot

Each type of weed seed was tested individually representing a block in which the mulches were replicated five times.

Experiment 3 consisted of spreading an actual layer of mulch 2.5 cm thick in the pots over the weed seeds. Distilled water with an average pH of 5.7 was used to water the mulched pots by the following schedule:

	Date	ml/pot
1987 December	9	150
	11	100
	13	30-50
	15	30
	17	30

The weeds were counted as they germinated and developed into seedlings and discarded.

Experiment 4 consisted of using leachate derived from the mulches to pour into pots containing weed seeds. The mulches were cut up with pruners and put in a plastic gallon jug with part of the top cut out leaving the pour spout intact. The volume was equal for each kind of mulch, which was determined by calculating the amount of mulch that would produce a 2.5cm thick layer over the weed seeds for a total of 15 pots (5 pots/weed type). The weights were then recorded for each mulch (Table 9). The jugs were filled with distilled water and due to the nature of the

Table 9. The dry weight in grams of the mulch treatments used for obtaining leachate in the greenhouse experiment 4.

Mulch Treatment	Dry Weight Grams
Pea Gravel	2549
White Oak Sawdust	820
Red Oak Bark	820
Red Oak Sawdust	811
White Oak Bark	740
Eastern Hemlock Foliage	509
Eastern Red Cedar Wood Chips	457
Eastern Red Cedar Foliage	290
Fresh White Pine Needles	283
Red Maple Leaves	263
Sassafras Leaves	193
Black Walnut Leaves	167
Black Cherry Leaves	165
Alfalfa	148
Hackberry Leaves	131
Black Walnut Wood Shavings	113
Old White Pine Needles	112
Johnsongrass	110
Wheat Straw	73
No Mulch	0

different kinds of mulches the amount of water to fill the jugs was not the same (2400-3000 ml) for each mulch. The mulch soaked in the water for 24 hours. Leachate was then filtered through a double layer of cheesecloth into a graduated 1000 ml cylinder and poured into a bucket. Soluble salt and pH readings were then recorded for each kind of leachate so that they could be correlated to germination.

The mulches were soaked in distilled water for 24 hours six additional times in order to provide more leachate for watering the weed seeds. This meant that the concentration of any chemicals present in the leachate was probably diluted at each soaking. All the leachate waterings were done in December of 1987 according to the following schedule:

Date	ml/pot
8	130
10	80
12	50
14,16,18,21	30

Weed seedlings were counted, removed from the sand and discarded. Therefore the data were based on the number of weeds that germinated and developed into seedlings. However, there was a problem with the morningglory seeds rolling around and uprooting the radicle tip when the leachate was poured into the pots. Gerimination was recorded even if no seedling actually developed.

Leachate from the first set of soakings was also used for a petri dish experiment containing the weed seeds and filter paper. The petri dishes were sealed with a thin strip of parafilm to eliminate excessive evaporation so that additional waterings of leachate would not be necessary. The experimental design was the same as for experiment 4 except the dishes were placed in a growth chamber. The block of dishes containing morningglory seeds required 3 ml of leachate/dish and 2 ml of leachate/dish for crabgrass and pigweed.

IV. RESULTS AND DISCUSSION

All data for the germination of weed seeds and the fresh weight of test plants were analyzed by ANOVA and the means separated by the Duncan's multiple range test at the five percent level of probability. The mulch treatments were compared to the control(s), inert pea gravel and/or no mulch, to determine which treatments were important in significantly inhibiting or enhancing germination of weed seeds and growth of ornamental plants by the possible release of allelochemicals. The control(s) had no known leachable allelochemicals so therefore, the mean number of weeds in the pea gravel was assigned as 100% germination. In experiment 4 there were two controls so the average of the two mean number of weeds was calculated and assigned 100% germination.

The treatments in experiment one were compared within two categories; wood products and straw mulch, and then compared over all treatments. The treatments in experiment two were compared within four categories; wood products, foliage mulch, straw mulch, and cut up herbaceous plant mulch and then compared over all treatments. Experiments three and four were compared within three categories; wood products, foliage mulch, and combined category of straw and cut up herbaceous plant mulch and then compared over all treatments. Also, an overall comparison of the three types of weeds within each experiment was performed to show which treatments acted similarly for all three weed types. Lastly, a comparison was made between the four experiments for the individual weed types and then for the three weeds combined to show if any of the mulches were consistant in their performance in all the experiments.

Experiment 1
1987 Summer Experiment

Weed Analysis

Morningglory (Table 10). The treatments of importance were black walnut leaves (49% germination) and wheat straw (59% germination) which significantly inhibited morningglory compared to the control (100% germination).

None of the wood products or the straw mulches were significantly different within their groups. On the other hand when the treatments were compared overall, the following significances occurred: (1) black walnut leaves significantly inhibited morningglory compared to yellow poplar sawdust, white oak sawdust, red oak sawdust, sugar maple sawdust, and pine bark; (2) wheat straw significantly inhibited morningglory compared to yellow poplar sawdust and white oak sawdust.

Table 10. The mean number of morningglory in each treatment for the 1987 summer field experiment, experiment 1.

Mulch Treatment	Mean Number of Weed[1] Morningglory
Yellow Poplar sawdust	49.5 a
White Oak sawdust	48.0 a
Pea Gravel (control)	46.2 a
Red Oak sawdust	44.5 ab
Sugar Maple sawdust	43.2 ab
Pine bark	42.5 ab
Pine sawdust	42.2 abc
Beech sawdust	40.0 abc
Sugar Maple bark	36.5 abc
White Oak bark	35.0 abc
Barley straw	34.2 abc
Beech bark	34.0 abc
No mulch	33.7 abc
Eastern Red Cedar wood chips	33.5 abc
Hickory bark	32.5 abc
Yellow Poplar bark	31.5 abc
Rye straw	30.0 abc
Red Oak bark	30.0 abc
Wheat straw	25.7 bc
Black Walnut leaves	22.7 c

[1]Means followed by the same letter are not significantly different at the 5% level of probability according to Duncan's multiple range test.

The bark mulches, excluding pine bark, and eastern red cedar wood chips fell below all of the sawdust mulches on the table. This type of separation signifies that a difference between the bark and sawdust mulches may exist. It is obvious that the physical nature of bark and sawdust is different. Sawdust is naturally made up of finer particles than bark and wood chips. Also the reason for pine bark not acting the same as the hardwood barks may be due to the fact that it naturally mills into finer particles than hardwood bark. If the separation of the bark and sawdust is due to allelochemicals it could be speculated that bark contains allelochemicals or that the allelochemicals are more easily leached from bark or the toxicity is greater. The case of eastern red cedar wood chips acting in the same manner as the bark mulches could be explained by the fact that the mulch contained bark pieces and allelochemicals.

Large Crabgrass (Table 11). The treatments of importance were barley straw (11% germination), eastern red cedar wood chips (13% germination), and rye straw (14% germination) which significantly inhibited large crabgrass compared to the control (100% germination).

White oak bark significantly inhibited germination compared to yellow poplar sawdust. Eastern red cedar wood chips significantly inhibited germination compared to

Table 11. The mean number of large crabgrass in each treatment for the 1987 summer field experiment, experiment 1.

Mulch Treatment	Mean Number of Weeds[1] Large Crabgrass
Yellow Poplar sawdust	115.0 a
Sugar Maple sawdust	108.5 ab
Pea Gravel (control)	108.0 ab
No mulch	98.5 ab
Hickory bark	92.5 abc
White Oak sawdust	83.5 abc
Pine sawdust	67.5 abc
Beech sawdust	64.0 abc
Red Oak bark	61.7 abc
Red Oak sawdust	61.5 abc
Sugar Maple bark	54.5 abc
Pine bark	47.5 abc
Black Walnut leaves	43.7 abc
Yellow Poplar bark	42.2 abc
Beech bark	35.2 abc
Wheat straw	31.0 bc
White Oak bark	25.7 bc
Rye straw	15.2 c
Eastern Red Cedar wood chips	14.2 c
Barley straw	12.2 c

[1]Means followed by the same letter are not significantly different at the 5% level of probability according to Duncan's multiple range test.

yellow poplar sawdust, sugar maple sawdust, and no mulch.

Wheat straw significantly inhibited germination compared to yellow poplar sawdust. Both barley straw and rye straw significantly inhibited germination compared to yellow poplar sawdust, sugar maple sawdust, and no mulch.

Hickory bark was very bulky, did not cover the soil very well, and provided results similar to no mulch treatment.

<u>Pigweed (Table 12).</u> The treatments of importance were rye straw (.24% germination), eastern red cedar wood chips (1.7% germination), and barley straw and wheat straw (5.6% germination) which significantly inhibited germination compared to the control (100% germination).

Among the wood products, eastern red cedar wood chips, red oak bark , beech bark, and pine bark significantly inhibited germination compared to sugar maple sawdust.

Rye straw, barley straw, wheat straw, and black walnut leaves significantly inhibited germination compared to sugar maple sawdust.

<u>Overall Comparison (Table 10, 11, and 12).</u> None of the treatments significantly inhibited all three weeds compared to the control. However, eastern red cedar wood chips, barley straw, and rye straw were common for

Table 12. The mean number of pigweed in each treatment for the 1987 summer field experiment, experiment 1.

Mulch Treatment	Mean Number of Weeds[1] Pigweed
Sugar Maple sawdust	117.2 a
Pea Gravel (control)	102.0 ab
Hickory bark	91.5 abc
Yellow Poplar sawdust	90.5 abc
Yellow Poplar bark	80.2 abc
Beech sawdust	73.2 abc
No mulch	72.7 abc
White Oak sawdust	70.0 abc
Red Oak sawdust	59.7 abc
Sugar Maple bark	42.2 abc
White Oak bark	39.7 abc
Pine sawdust	29.2 abc
Pine bark	24.5 bc
Beech bark	14.5 bc
Black Walnut leaves	12.7 bc
Red Oak bark	12.0 bc
Wheat straw	5.7 c
Barley straw	5.7 c
Eastern Red Cedar wood chips	1.7 c
Rye straw	0.2 c

[1]Means followed by the same letter are not significantly different at the 5% level of probability according to Duncan`s multiple range test.

significantly inhibiting both large crabgrass and pigweed. Wheat straw was common for significantly inhibiting morningglory and pigweed. The number of straw mulches that were significant for inhibiting morningglory, large crabgrass, and pigweed increased from one to three respectively. Therefore, if allelochemicals were responsible for causing these mulches to be significant, the reason for not being significant for all three weeds may be due to the individual sensitivity of each weed.

Fresh Weight Analysis

Sunflower (Table 13). The mean grams of fresh weight ranged from 481.7 (white oak sawdust) to 180.7 (sugar maple sawdust). None of the treatments significantly inhibited or enhanced growth compared to the control. Two treatments, sugar maple sawdust and red oak bark, significantly inhibited growth compared to white oak sawdust.

Marigold (Table 14). The mean grams of fresh weight ranged from 238.7 (beech sawdust) to 144.2 (no mulch). None of the treatments significantly inhibited growth compared to the control or any other treatments.

Willow (Table 15). The mean grams of fresh weight ranged from 17 (beech bark) to .2 (barley straw). None of the treatments significantly inhibited growth compared to the control. However, barley straw and red oak bark

Table 13. The mean grams of sunflower fresh weight in each mulch treatment for the 1987 summer field experiment, experiment 1.

	Mean Grams of Fresh Weight[1]
Mulch Treatment	Sunflower
White Oak sawdust	481.7 a
Sugar Maple bark	426.0 ab
Rye straw	399.5 ab
Yellow Poplar sawdust	391.7 ab
Yellow Poplar bark	362.7 ab
Black Walnut leaves	360.0 ab
Beech sawdust	350.2 ab
No mulch	349.2 ab
Eastern Red Cedar wood chips	327.3 ab
Barley straw	319.5 ab
Red Oak sawdust	313.7 ab
White Oak bark	290.5 ab
Wheat straw	284.3 ab
Pine sawdust	277.0 ab
Pea Gravel (control)	251.2 ab
Pine bark	248.2 ab
Beech bark	239.2 ab
Hickory bark	236.0 ab
Red Oak bark	181.0 b
Sugar Maple sawdust	180.7 b

[1]Means followed by the same letter are not significantly different at the 5% level of probability according to Duncan`s multiple range test.

Table 14. The mean grams of marigold fresh weight in each mulch treatment for the 1987 summer field experiment, experiment 1.

Mulch Treatment	Mean Grams of Fresh Weight[1] Marigold
Beech sawdust	238.7 a
Beech bark	232.0 a
Eastern Red Cedar wood chips	230.5 a
Yellow Poplar sawdust	228.7 a
Sugar Maple sawdust	221.2 a
Wheat straw	214.0 a
Black Walnut leaves	210.0 a
Yellow Poplar bark	207.0 a
Pine sawdust	206.2 a
Rye straw	198.0 a
Red Oak sawdust	193.7 a
Pea Gravel (control)	193.2 a
White Oak bark	192.0 a
Barley straw	191.2 a
White Oak sawdust	189.7 a
Pine bark	188.0 a
Red Oak bark	181.7 a
Sugar Maple bark	178.2 a
Hickory bark	149.0 a
No mulch	144.2 a

[1]Means followed by the same letter are not significantly different at the 5% level of probability according to Duncan's multiple range test.

Table 15. The mean grams of 'Brilliant' willow fresh weight in each mulch treatment for the 1987 summer field experiment, experiment 1.

Mulch Treatment	Mean Grams of Fresh Weight[1] 'Brilliant' Willow
Beech bark	17.0 a
White Oak bark	15.7 ab
Beech sawdust	13.7 abc
Pea Gravel (control)	10.5 abc
Sugar Maple sawdust	9.7 abc
Eastern Red Cedar wood chips	9.2 abc
Yellow Poplar bark	8.0 abc
Sugar Maple bark	8.0 abc
White Oak sawdust	7.7 abc
Pine sawdust	7.7 abc
Red Oak sawdust	7.0 abc
Yellow Poplar sawdust	7.0 abc
Black Walnut leaves	6.2 abc
Hickory bark	5.7 abc
No mulch	5.5 abc
Pine bark	4.2 abc
Rye straw	2.5 abc
Wheat straw	2.2 bc
Red Oak bark	0.7 c
Barley straw	0.2 c

[1]Means followed by the same letter are not significantly different at the 5% level of probability according to Duncan's multiple range test.

significantly inhibited growth compared to beech bark and white oak bark. Wheat straw significantly inhibited growth compared to beech bark.

<u>Cotoneaster (Table 16).</u> The mean grams of fresh weight ranged from 8.5 (eastern red cedar wood chips) to 0.0 (barley straw). None of the treatments significantly inhibited growth compared to the control. However, barley straw, sugar maple sawdust, red oak sawdust, and wheat straw significantly inhibited growth compared to eastern red cedar wood chips. Barley straw and sugar maple sawdust significantly inhibited growth compared to no mulch. Barley straw also inhibited growth compared to beech bark.

<u>Crapemyrtle (Table 17).</u> The mean grams of fresh weight ranged from 31 (eastern red cedar wood chips) to 8.2 (yellow poplar sawdust). None of the treatments significantly inhibited growth compared to the control or any other treatments.

<u>Red Maple (Table 18).</u> The mean grams of fresh weight ranged from 4 (beech bark) to .5 (wheat straw). Wheat straw significantly inhibited the growth compared to the control. Red maple was the only test plant that was significantly inhibited compared to the control.

Black walnut leaves, barley straw, and beech sawdust significantly inhibited growth compared to beech bark and

Table 16. The mean grams of bearberry cotoneaster fresh weight in each mulch treatment for the 1987 summer field experiment, experiment 1.

Mulch Treatment	Mean Grams of Fresh Weight[1] Bearberry Cotoneaster
Eastern Red Cedar wood chips	8.5 a
No mulch	7.2 ab
Beech bark	6.0 abc
Red Oak bark	5.5 abcd
White Oak bark	5.2 abcd
Pine sawdust	5.0 abcd
White Oak sawdust	4.5 abcd
Hickory bark	4.5 abcd
Yellow Poplar sawdust	4.2 abcd
Yellow Poplar bark	4.2 abcd
Black Walnut leaves	3.7 abcd
Pine bark	3.7 abcd
Beech sawdust	3.5 abcd
Pea Gravel (control)	3.3 abcd
Sugar Maple bark	3.0 abcd
Rye straw	2.7 abcd
Wheat straw	2.5 bcd
Red Oak sawdust	2.2 bcd
Sugar Maple sawdust	1.2 cd
Barley straw	0.0 d

[1]Means followed by the same letter are not significantly different at the 5% level of probability according to Duncan`s multiple range test.

Table 17. The mean grams of common crapemyrtle fresh weight in each mulch treatment for the 1987 summer field experiment, experiment 1.

Mulch Treatment	Mean Grams of Fresh Weight[1]
	Common Crapemyrtle
Eastern Red Cedar wood chips	31.0 a
Sugar Maple sawdust	29.7 a
No mulch	26.0 a
Red Oak sawdust	25.5 a
Wheat straw	25.5 a
Pea Gravel (control)	25.2 a
Beech sawdust	24.0 a
White Oak bark	23.7 a
Yellow Poplar bark	23.5 a
Sugar Maple bark	21.2 a
Red Oak bark	17.7 a
Black Walnut leaves	17.7 a
Rye straw	17.5 a
White Oak sawdust	16.5 a
Pine sawdust	14.5 a
Beech bark	14.0 a
Hickory bark	13.0 a
Pine bark	12.0 a
Barley straw	11.0 a
Yellow Poplar sawdust	8.2 a

[1]Means followed by the same letter are not significantly different at the 5% level of probability according to Duncan`s multiple range test.

Table 18. The mean grams of red maple fresh weight in each mulch treatment for the 1987 summer field experiment, experiment 1.

Mulch Treatment	Mean Grams of Fresh Weight[1]
	Red Maple
Beech bark	4.0 a
Eastern Red Cedar wood chips	3.7 a
Sugar Maple sawdust	3.5 ab
White Oak bark	3.2 ab
Pea Gravel (control)	3.0 abc
Yellow Poplar bark	2.7 abc
Pine sawdust	2.7 abc
Hickory bark	2.7 abc
Yellow Poplar sawdust	2.7 abc
Red Oak bark	2.7 abc
Pine bark	2.5 abc
Sugar Maple bark	2.5 abc
No mulch	2.5 abc
Red Oak sawdust	2.2 abc
White Oak sawdust	2.2 abc
Rye straw	2.2 abc
Beech sawdust	1.7 bcd
Barley straw	1.2 cd
Black Walnut leaves	1.2 cd
Wheat straw	0.5 d

[1]Means followed by the same letter are not significantly different at the 5% level of probability according to Duncan`s multiple range test.

eastern red cedar wood chips. Black walnut leaves and barley straw significantly inhibited growth compared to sugar maple sawdust and white oak bark. Wheat straw significantly inhibited growth compared to all other treatments except for beech sawdust, barley straw, and black walnut leaves.

Overall Comparison (Tables 10-p.34, 11-p.36, 12-p.38, 13-p.40, 14-p.41, 15, 16, 17, and 18). Eastern red cedar wood chips did not significantly inhibit the growth of the ornamental test plants, but did significantly inhibit the germination of large crabgrass and pigweed. Therefore, eastern red cedar wood chips tended to promote good growth of the test plants and controlled weeds.

Wheat straw was the only mulch that both significantly inhibited the growth of red maple and germination of weeds compared to the control. Thus, suggesting that wheat straw controlled weeds but also could inhibit the growth of ornamental plants depending upon the species.

Experiment 2
1987 - 1988 Overwintering Study

Weed Analysis

Morningglory (Table 19). All treatments except old white pine needles, eastern red cedar wood chips, hackberry

Table 19. The mean number of morningglory in each treatment for the 1987 - 1988 overwintering field experiment, experiment 2.

Mulch Treatment	Mean Number of Weeds[1] Morningglory
Pea Gravel (control)	7.3 a
Old White Pine needles	6.2 ab
Eastern Red Cedar wood chips	5.2 abc
Hackberry leaves	5.2 abc
Black Cherry leaves	4.8 abcd
Eastern Red Cedar foliage	4.3 bcde
Sugar Maple sawdust	4.2 bcde
Fresh White Pine needles	4.0 bcdef
White Oak sawdust	4.0 bcdef
Red Maple leaves	3.7 bcdefg
Black Walnut leaves	3.7 bcdefg
Alfalfa	3.5 bcdefg
White Oak bark	3.3 bcdefgh
Sassafras leaves	3.2 cdefgh
Red Oak sawdust	3.2 cdefgh
Pokeweed	3.2 cdefgh
No mulch	2.3 cdefgh
Red Oak bark	2.2 defgh
Oat straw	2.0 defgh
Johnsongrass	1.5 efgh
Black Walnut wood shavings	1.2 fgh
Wheat straw	1.0 gh
Eastern Hemlock foliage	1.0 gh

[1]Means followed by the same letter are not significantly different at the 5% level of probability according to Duncan`s multiple range test.

leaves, and black cherry leaves significantly inhibited germination compared to the control. The treatments of most importance compared to the control (100% germination), ranged from 59% for eastern red cedar foliage to 14% for eastern hemlock foliage. Since the majority of the mulches significantly inhibited morningglory and the control occurred at the top of the table, it could mean that allelochemicals were responsible for such low germination. However, the temperature could have been a factor also. Rain provided plenty of water for the morningglory seeds soon after they were sown. Also the temperature remained warm (+ or - 60 degrees F.) for about a week and then dropped substantially. Morningglory germinates within 24 hours when plenty of water and warm temperatures are available.

Among the wood products, black walnut wood shavings significantly inhibited germination compared to eastern red cedar wood chips and sugar maple sawdust. Red oak bark significantly inhibited germination compared to eastern red cedar wood chips. In addition, red oak bark and red oak sawdust significantly inhibited germination compared to old white pine needles. Red oak bark significantly inhibited germination compared to hackberry leaves. Black walnut wood shavings significantly inhibited germination compared to old white pine needles, hackberry leaves, black cherry leaves, and eastern red cedar foliage.

Among the foliage treatments, eastern hemlock foliage significantly inhibited germination compared to old white pine needles, hackberry leaves, black cherry leaves, eastern red cedar foliage, and fresh white pine needles. Sassafras leaves significantly inhibited germination compared to old white pine needles. In addition, eastern hemlock foliage significantly inhibited germination compared to eastern red cedar wood chips, sugar maple sawdust, and white oak sawdust. Therefore, eastern hemlock foliage significantly inhibited germination compared to nine of the other treatments.

Oat and wheat straw significantly inhibited germination compared to old white pine needles, eastern red cedar wood chips, and hackberry leaves. Wheat straw significantly inhibited germination compared to old white pine needles, eastern red cedar wood chips, hackberry leaves, black cherry leaves, eastern red cedar foliage, sugar maple sawdust, fresh white pine needles, and white oak sawdust. Therefore wheat straw significantly inhibited morningglory compared to the same nine treatments that eastern hemlock foliage was significantly different from.

Pokeweed significantly inhibited germination compared to old white pine needles, and johnsongrass significantly inhibited germination compared to old white pine needles, eastern red cedar wood chips, hackberry leaves, and black cherry leaves.

Large Crabgrass (Table 20). None of the treatments significantly inhibited germination compared to the control. As a matter of fact johnsongrass and pokeweed occurred first and second on the table and significantly enhanced crabgrass germination compared to the control and all other treatments. For some reason crabgrass germinated better under johnsongrass and pokeweed than any other treatments. This can not be explained, but it was speculated that the overwintering process encouraged the effect of the allelochemicals of the other mulches and possibly provided an inhibitory environment for pea gravel. The physical nature of the two mulches would not seem to be a factor since johnsongrass was not comparable to pokeweed.

Sugar maple sawdust, white oak sawdust, white oak bark, and red oak sawdust significantly inhibited germination compared to black walnut leaves, hackberry leaves, and fresh white pine needles. Black walnut wood shavings, red oak bark, and eastern red cedar wood chips significantly inhibited germination compared to black walnut leaves and hackberry leaves.

Among the foliage treatments eastern hemlock foliage and sassafras leaves significantly inhibited germination compared to black walnut leaves, hackberry leaves, and

Table 20. The mean number of large crabgrass in each treatment for the 1987 - 1988 overwintering field experiment, experiment 2.

Mulch Treatment	Mean Number of Weeds[1] Large Crabgrass
Johnsongrass	21.2 a
Pokeweed	15.5 b
Black Walnut leaves	7.7 c
Hackberry leaves	6.5 cd
Fresh White Pine needles	5.5 cde
Pea Gravel (control)	4.3 cdef
Alfalfa	4.2 cdef
Black Cherry leaves	3.7 def
No mulch	2.8 def
Eastern Red Cedar foliage	2.3 ef
Old White Pine needles	2.0 ef
Oat straw	1.8 ef
Eastern Red Cedar wood chips	1.7 ef
Red Oak bark	1.7 ef
Red Maple leaves	1.5 ef
Black Walnut wood shavings	1.3 ef
Red Oak sawdust	1.2 f
White Oak bark	1.2 f
White Oak sawdust	0.7 f
Sassafras leaves	0.5 f
Wheat straw	0.2 f
Sugar Maple sawdust	0.2 f
Eastern Hemlock foliage	0.2 f

[1]Means followed by the same letter are not significantly different at the 5% level of probability according to Duncan`s multiple range test.

fresh white pine needles. Red maple leaves, old white pine needles, and eastern red cedar foliage significantly inhibited germination compared to black walnut leaves and hackberry leaves. Black cherry leaves significantly inhibited germination compared to black walnut leaves.

Wheat straw significantly inhibited germination compared to black walnut leaves, hackberry leaves, and fresh white pine needles. Oat straw significantly inhibited germination compared to black walnut leaves and hackberry leaves.

Among the herbaceous plant mulches alfalfa significantly inhibited germination compared to johnsongrass and pokeweed.

Therefore, even though none of the treatments significantly inhibited large crabgrass compared to the control, all the treatments significantly inhibited germination compared to johnsongrass and pokeweed. In addition most of the treatments were also significantly different from black walnut leaves and hackberry leaves.

Pigweed (Table 21). Sugar maple sawdust, black walnut wood shavings, and white oak bark significantly inhibited germination compared to the control. The treatments of importance compared to the control (100% germination), ranged from 11% for red oak sawdust to 3.5% for sugar maple sawdust. All treatments significantly inhibited germination

Table 21. The mean number of pigweed in each treatment for the 1987 - 1988 overwintering field experiment, experiment 2.

Mulch Treatment	Mean Number of Weeds[1]
	Pigweed
Pokeweed	37.0 b
Alfalfa	31.5 b
Fresh White Pine needles	21.0 c
Black Walnut leaves	20.3 c
Hackberry leaves	14.7 cd
Eastern Hemlock foliage	12.7 de
Old White Pine needles	11.0 def
Johnsongrass	10.7 def
Oat straw	10.5 def
Pea Gravel (control)	9.3 defg
Red Maple leaves	8.2 defgh
Black Cherry leaves	8.0 defgh
Eastern Red Cedar foliage	8.0 defgh
No mulch	5.0 efgh
Eastern Red Cedar wood chips	4.7 fgh
Wheat straw	4.3 fgh
White Oak sawdust	2.3 gh
Red Oak bark	2.3 gh
Sassafras leaves	2.0 gh
Red Oak sawdust	1.0 gh
White Oak bark	1.0 h
Black Walnut wood shavings	0.3 h
Sugar Maple sawdust	0.3 h

[1]Means followed by the same letter are not significantly different at the 5% level of probability according to Duncan's multiple range test.

compared to pokeweed and alfalfa. On the other hand, pokeweed, alfalfa, fresh white pine needles, and black walnut leaves significantly enhanced germination compared to the control. Once again this provided a situation that was hard to explain. Maybe leaching during the winter removed or biodegraded any possible allelochemicals or/and created germination enhancing factors or/and conversion of inhibitory chemicals to germination promoting chemicals.

Sugar maple sawdust, black walnut wood shavings, white oak bark, red oak sawdust, red oak bark, and white oak sawdust significantly inhibited germination compared to fresh white pine needles, black walnut leaves, hackberry leaves, eastern hemlock foliage, old white pine needles, johnsongrass, and oat straw. Eastern red cedar wood chips significantly inhibited germination compared to fresh white pine needles, black walnut leaves, hackberry leaves, and eastern hemlock foliage.

Among the foliage treatments sassafras leaves significantly inhibited germination compared to fresh white pine needles, black walnut leaves, hackberry leaves, eastern hemlock foliage, and old white pine needles. Eastern red cedar foliage, black cherry leaves, red maple leaves, old white pine needles, and eastern hemlock foliage significantly inhibited germination compared to fresh white pine needles and black walnut leaves. In addition, sassafras leaves significantly inhibited germination compared to johnsongrass and oat straw.

Wheat straw significantly inhibited germination compared to fresh white pine needles, black walnut leaves, hackberry leaves, and eastern hemlock foliage. Oat straw significantly inhibited germination compared to fresh white pine needles and black walnut leaves.

Johnsongrass significantly inhibited germination compared to pokeweed and alfalfa just as did all the other treatments. Also johnsongrass significantly inhibited germination compared to fresh white pine needles and black walnut leaves.

Therefore, all the treatments except hackberry leaves significantly inhibited germination compared to pokeweed, alfalfa, fresh white pine needles, and black walnut leaves which significantly enhanced germination compared to the control.

<u>Overall Comparison (Table 19-p.48, 20, and 21).</u> Large crabgrass analysis was not used in this comparison for treatments that signigicantly inhibited germination compared to the control, since none of the treatments significantly inhibited large crabgrass. Four treatments, sugar maple sawdust, black walnut wood shavings, white oak bark, and red oak sawdust significantly inhibited both pigweed and morningglory compared to the control.

Fresh Weight Analysis

Cotoneaster (Table 22). The mean grams of fresh weight ranged from 23.2 (eastern red cedar wood chips) to 2.4 (no mulch). The no mulch treatment and alfalfa significantly inhibited growth compared to the control. The no mulch treatment also significantly inhibited growth compared to eastern red cedar wood chips, sassafras leaves, hackberry leaves, red maples leaves, red oak bark, and black cherry leaves. Since no mulch conditions provided less protection from environmental conditions and less moisture these results might be expected. Also cotoneaster may be more sensitive to allelochemicals released from alfalfa than from the other mulches.

Among the wood products black walnut wood shavings, sugar maple sawdust, white oak sawdust, white oak bark, and red oak sawdust significantly inhibited growth compared to eastern red cedar wood chips. In addition, black walnut wood shavings significantly inhibited growth compared to sassafras leaves and hackberry leaves. Sugar maple sawdust significantly inhibited growth compared to sassafras leaves.

Among the foliage treatments old white pine needles significantly inhibited growth compared to sassafras leaves and hackberry leaves. Eastern hemlock foliage significantly inhibited growth compared to sassafras leaves. In addition,

Table 22. The mean grams of pyrenees cotoneaster fresh weight in each treatment for the 1987 - 1988 overwintering field experiment, experiment 2.

Mulch Treatment	Mean Grams of Fresh Weight[1] Pyrenees Cotoneaster
Eastern Red Cedar wood chips	23.1 a
Sassafras leaves	20.9 ab
Hackberry leaves	19.4 abc
Pea Gravel (control)	15.5 abcd
Red Maple leaves	14.7 abcde
Red Oak bark	13.8 abcde
Black Cherry leaves	13.5 abcde
Fresh White Pine needles	13.2 abcdef
Black Walnut leaves	12.6 bcdef
Eastern Red Cedar foliage	11.7 bcdefg
Red Oak sawdust	11.5 bcdefg
White Oak bark	11.3 bcdefg
White Oak sawdust	11.0 bcdefg
Johnsongrass	10.5 bcdefg
Eastern Hemlock foliage	9.8 cdefg
Sugar Maple sawdust	8.8 cdefg
Oat straw	8.4 defg
Wheat straw	7.5 defg
Black Walnut wood shavings	7.3 defg
Old White Pine needles	6.9 defg
Pokeweed	6.0 defg
Alfalfa	3.9 efg
No mulch	2.4 fg

[1]Means followed by the same letter are not significantly different at the 5% level of probability according to Duncan's multiple range test.

old white pine needles, eastern hemlock foliage, eastern red cedar foliage, and black walnut leaves significantly inhibited growth compared to eastern red cedar wood chips.

Oat and wheat straw significantly inhibited growth compared to eastern red cedar wood chips, sassafras leaves, and hackberry leaves. Possibly cotoneaster is sensitive to straw allelochemicals in general.

Alfalfa significantly inhibited growth compared to eastern red cedar wood chips, sassafras leaves, and hackberry leaves. Pokeweed significantly inhibited growth compared to eastern red cedar wood chips, sassafras leaves, and hackberry leaves. Johnsongrass significantly inhibited growth compared to eastern red cedar wood chips.

Therefore, only two treatments significantly inhibited growth of cotoneaster compared to the control. However, most of the treatments significantly inhibited growth compared to eastern red cedar wood chips and sassafras leaves.

<u>Dogwood (Table 23).</u> The mean grams of fresh weight ranged from 45.2 (red maple leaves) to 15.9 (pokeweed) None of the treatments significantly inhibited growth compared to the control.

Red oak bark significantly inhibited growth compared to red maple leaves.

Among the foliage treatments, eastern red cedar

Table 23. The mean grams of flowering dogwood fresh weight in each treatment for the 1987 - 1988 overwintering field experiment, experiment 2.

Mulch Treatment	Mean Grams of Fresh Weight[1]
	Flowering Dogwood
Red Maple leaves	45.2 a
Black Walnut wood shavings	43.1 ab
Eastern Hemlock foliage	39.0 abc
Fresh White Pine needles	36.6 abc
Sugar Maple sawdust	39.0 abc
Pea Gravel (control)	35.0 abcd
No mulch	34.3 abcd
Black Cherry leaves	31.5 abcd
Eastern Red Cedar wood chips	29.7 abcde
White Oak sawdust	28.4 abcde
Johnsongrass	27.6 abcde
White Oak bark	27.2 abcde
Hackberry leaves	27.0 abcde
Sassafras leaves	26.6 abcde
Wheat straw	26.4 abcde
Red Oak sawdust	25.5 abcde
Red Oak bark	25.1 bcde
Black Walnut leaves	25.1 bcde
Old White Pine needles	23.1 bcde
Oat straw	21.3 cde
Alfalfa	20.4 cde
Eastern Red Cedar foliage	18.9 cde
Pokeweed	15.9 de

[1]Means followed by the same letter are not significantly different at the 5% level of probability according to Duncan`s multiple range test.

foliage, old white pine needles, and black walnut leaves significantly inhibited growth compared to red maple leaves. Eastern red cedar foliage significantly inhibited growth compared to black walnut wood shavings.

Oat straw significantly inhibited growth compared to red maple leaves and black walnut wood shavings.

Pokeweed significantly inhibited growth compared to red maple leaves, black walnut wood shavings, eastern hemlock foliage, fresh white pine needles, and sugar maple sawdust. Alfalfa significantly inhibited growth compared to red maple leaves and black walnut wood shavings.

Therefore, none of the treatments significantly inhibited growth compared to the control. However, several of the treatments significantly inhibited growth compared to red maple leaves and black walnut leaves.

Euonymus (Table 24). The mean grams of fresh weight ranged from 12.1 (pokeweed) to 6.0 (sugar maple sawdust). Sugar maple sawdust, red oak sawdust, white oak bark, and wheat straw significantly inhibited growth compared to the control. The plants had severely yellowed in the sawdust treatments, presumedly due to the carbon:nitrogen ratio of sawdust.

Sugar maple sawdust, red oak sawdust, and white oak bark significantly inhibited growth compared to pokeweed, alfalfa, eastern hemlock foliage, and johnsongrass.

Table 24. The mean grams of 'Compactus' euonymus fresh weight in each treatment for the 1987 - 1988 overwintering field experiment, experiment 2.

Mulch Treatment	Mean Grams of Fresh Weight[1] 'Compactus' Euonymus
Pokeweed	12.1 a
Pea Gravel (control)	11.7 ab
Alfalfa	11.6 abc
Eastern Hemlock foliage	11.5 abc
Johnsongrass	11.2 abc
Fresh White Pine needles	10.1 abcd
Hackberry leaves	10.0 abcd
Red Maple leaves	9.8 abcd
Eastern Red Cedar wood chips	9.7 abcd
Black Walnut wood shavings	9.7 abcd
Black Cherry leaves	9.5 abcd
Black Walnut leaves	9.0 abcd
Red Oak bark	8.8 abcd
Old White Pine needles	8.8 abcd
Eastern Red Cedar foliage	8.7 abcd
White Oak sawdust	8.1 abcd
No mulch	7.9 abcd
Oat straw	7.8 bcd
Sassafras leaves	7.6 bcd
Wheat straw	7.2 cd
White Oak bark	6.6 d
Red Oak sawdust	6.3 d
Sugar Maple sawdust	6.0 d

[1]Means followed by the same letter are not significantly different at the 5% level of probability according to Duncan's multiple range test.

Sassafras leaves significantly inhibited growth compared to pokeweed.

Wheat and oat straw significantly inhibited growth compared to pokeweed.

The herbaceous plant mulches did not significantly inhibit growth compared to each other or any other treatments. Pokeweed and alfalfa occurred together at the top of the table with the control. Thus, if allelochemicals were released from these two mulches they did not adversely affect the growth of euonymus.

Therefore, four mulches significantly inhibited the growth of euonymus compared to the control and other treatments. The two sawdust treatments probably inhibited the growth due to the carbon:nitrogen ratio of sawdust. The remaining two treatments, white oak bark and wheat straw possibly released herbicidal allelochemicals. In addition, two other mulches, sassafras leaves and oat straw significantly inhibited growth compared to pokeweed. The physical nature of the these mulches are distinctively different suggesting that other factors such as allelochemicals are responsible for inhibiting growth.

Holly (Table 25). The mean grams of fresh weight ranged from 12.1 (eastern red cedar wood chips) to 4.9 (white oak sawdust). None of the treatments significantly inhibited growth compared to the control. However, eastern

Table 25. The mean grams of 'Blue Girl' holly fresh weight in each treatment for the 1987 - 1988 overwintering field experiment, experiment 2.

Mulch Treatment	Mean Grams of Fresh Weight[1] 'Blue Girl' Holly
Eastern Red Cedar wood chips	12.1 a
Sassafras leaves	10.1 ab
Red Oak bark	10.0 ab
Hackberry leaves	9.7 abc
Alfalfa	9.7 abc
Red Maple leaves	9.4 abcd
Eastern Hemlock foliage	9.3 abcd
White Oak bark	8.8 abcde
Johnsongrass	8.2 bcdef
Pea Gravel (control)	8.2 bcdef
Black Walnut wood shavings	8.1 bcdef
Fresh White Pine needles	7.7 bcdef
Black Cherry leaves	7.7 bcdef
Oat straw	7.3 bcdef
Old White Pine needles	7.0 bcdef
Pokeweed	6.7 bcdef
No mulch	6.5 bcdefg
Red Oak sawdust	6.0 cdefg
Black Walnut leaves	5.7 defg
Eastern Red Cedar foliage	5.7 defg
Wheat straw	5.3 efg
Sugar Maple sawdust	5.0 efg
White Oak sawdust	4.9 fg

[1]Means followed by the same letter are not significantly different at the 5% level of probability according to Duncan`s multiple range test.

red cedar wood chips significantly enhanced growth compared to the control. The no mulch treatment significantly inhibited growth compared to eastern red cedar wood chips.

Among the wood products, white oak sawdust significantly inhibited growth compared to eastern red cedar wood chips, red oak bark, and white oak bark. Sugar maple sawdust and red oak sawdust significantly inhibited growth compared to eastern red cedar wood chips and red oak bark. Black walnut wood shavings significantly inhibited growth compared to eastern red cedar wood chips. In addition, white oak sawdust and sugar maple sawdust significantly inhibited growth compared to sassafras leaves, hackberry leaves, alfalfa, red maple leaves, and eastern hemlock foliage. Red oak sawdust significantly inhibited growth compared to sassafras leaves.

Among the foliage treatments, eastern red cedar foliage and black walnut leaves significantly inhibited growth compared to sassafras leaves and hackberry leaves. In addition, eastern red cedar foliage and black walnut leaves inhibited growth compared to eastern red cedar wood chips, red oak bark, and alfalfa. Old white pine needles, black cherry leaves, and fresh white pine needles significantly inhibited growth compared to eastern red cedar wood chips.

Wheat straw significantly inhibited growth compared to eastern red cedar wood chips, sassafras leaves, red oak bark, hackberry leaves, alfalfa, red maple leaves, and eastern hemlock foliage. Oat straw significantly inhibited growth compared to eastern red cedar wood chips.

Pokeweed and johnsongrass significantly inhibited growth compared to eastern red cedar wood chips.

Therefore, even though none of the treatments significantly inhibited the growth of holly compared to the control, fourteen treatments significantly inhibited growth compared to eastern red cedar wood chips. Six of these treatments also significantly inhibited growth compared to several other treatments.

Overall Comparison (Tables 19-p.48, 20-p.52, 21-p.54, 22-p.58, 23-p.60, 24, and 25). White oak bark, sugar maple sawdust, and black walnut wood shavings were commmon for significantly inhibiting morningglory and pigweed but not cotoneaster, dogwood, and holly. Also, black walnut wood shavings did not significantly inhibit the growth of eounymus.

Comparison of Experiment 1 and 2

Of the many treatments that were tested in both experiments ten were the same and these were the ones used for comparison: pea gravel, no mulch, red oak bark, red oak sawdust, white oak bark, white oak sawdust, sugar maple sawdust, eastern red cedar wood chips, wheat straw, and black walnut leaves. Also, cotoneaster was tested in both experiments but not the same species.

Variables encountered in experiment 1 included the types of mulches tested, the number of replications (4), the time of year at which the experiment was installed (summer), manually sowing the weeds with a Ortho Whirlybird seeder over the entire experimental field site, and artificially watering the site with a sprinkler. In comparison, for experiment 2 the variables included the types of mulches tested, the number of replications (6), the time of year the experiment was installed (winter), manually spreading by hand a predetermined number of weed seeds into each plot, and reliance only on the natural rainfall to water the site.

Morningglory (Tables 10-p.34 and 19-p.48). Wheat straw and black walnut leaves significantly inhibited germination of morningglory in both experiments compared to the control. These two treatments were the only treatments significant in experiment 1, however six other treatments were significant in experiment 2. Therefore, the variables played a big role in the reaction of the morningglory seeds.

Large Crabgrass (Tables 11-p.36 and 20-p.52). None of the treatments were common in both experiments for significantly inhibiting germination of crabgrass compared to the control, since none were significant in experiment 2. However eastern red cedar wood chips significantly inhibited germination in experiment 1 compared to the control and in experiment 2 compared to black walnut leaves.

Pigweed (Tables 12-p.38 and 21-p.54). None of the treatments were common for significantly inhibiting germination of pigweed compared to the control. Red oak bark, eastern red cedar wood chips, and wheat straw significantly inhibited germination in experiment 2 compared to black walnut leaves and in experiment 1 compared to sugar maple sawdust. Also in experiment 2 more of the treatments significantly inhibited germination compared to treatments other than the control. Once again the variables played a big role in the reaction of the pigweed seeds.

Cotoneaster (Tables 16-p.44 and 22-p.58). None of the treatments were common for inhibiting growth of cotoneaster compared to the control since none were significant in experiment 1. However, for both experiments red oak sawdust, sugar maple sawdust, and wheat straw inhibited growth compared to eastern red cedar wood chips. This suggested that cotoneaster was not affected differently by these treatments even though the variables differed between experiments.

Experiment 3
Greenhouse Mulch Study

Weed Analysis

Morningglory (Table 26). Eleven of the treatments, alfalfa, black cherry leaves, red maple leaves, eastern red cedar foliage, eastern hemlock foliage, old white pine needles, no mulch, hackberry leaves, sassafras leaves, fresh white pine needles, and black walnut wood shavings significantly inhibited germination compared to the control. The treatments of importance to the control (100% germination), ranged from 83% for black walnut wood shavings to 62% for alfalfa. Due to more control of the environmental factors in the greenhouse there was a greater chance for the mulches to effect the weed seeds more consistantly.

The no mulch treatment significantly inhibited germination compared to eastern red cedar wood chips. The reason for this was probably due to the watering technique. When the water was poured over the sand the seeds freely rolled around preventing the radicle from anchoring.

Table 26. The mean number of morningglory in each treatment for the greenhouse mulch layer experiment, experiment 3.

Mulch Treatment	Mean Number of Weeds[1]
	Morningglory
Pea Gravel (control)	32.6 a
Eastern Red Cedar wood chips	31.6 ab
Red Oak bark	30.6 abc
White Oak sawdust	30.0 abcd
Red Oak sawdust	29.6 abcd
White Oak bark	29.2 abcde
Johnsongrass	28.6 abcdef
Black Walnut leaves	28.2 abcdefg
Wheat straw	28.2 abcdefg
Black Walnut wood shavings	27.2 bcdefg
Fresh White Pine needles	26.6 bcdefg
Sassafras leaves	26.6 bcdefg
Hackberry leaves	26.0 cdefg
No mulch	26.0 cdefg
Old White Pine needles	25.2 defg
Eastern Hemlock foliage	24.2 efgh
Eastern Red Cedar foliage	23.8 fgh
Red Maple leaves	23.4 fgh
Black Cherry leaves	23.2 gh
Alfalfa	20.2 h

[1]Means followed by the same letter are not significantly different at the 5% level of probability according to Duncan`s multiple range test.

Black walnut wood shavings significantly inhibited germination compared to the control as mentioned early. Apparently under greenhouse conditions most of the wood products had no effect on morningglory.

Black cherry leaves significantly inhibited germination compared to eastern red cedar wood chips, red oak bark, white oak sawdust, red oak sawdust, white oak bark, and johnsongrass. Eastern red cedar foliage and red maple leaves significantly inhibited germination compared to eastern red cedar wood chips, red oak bark, white oak sawdust, red oak sawdust, and white oak bark. Eastern hemlock foliage significantly inhibited germination compared to eastern red cedar wood chips, red oak bark, white oak sawdust, and red oak sawdust. Old white pine needles significantly inhibited germination compared to eastern red cedar wood chips and red oak bark. Hackberry leaves significantly inhibited germination compared to eastern red cedar wood chips. Apparently greenhouse conditions enhanced the effect of the foliage mulches on morningglory.

Among the straw and herbceous plant mulches, alfalfa significantly inhibited germination compared to johnsongrass and wheat straw. Alfalfa also significantly inhibited germination compared to all other treatments except eastern hemlock foliage, eastern red cedar foliage, red maple leaves, and black cherry leaves. Greenhouse conditions definitely enhanced the effect of alfalfa but did not for either johnsongrass or wheat straw.

Large Crabgrass (Table 27). All the treatments except for no mulch, old white pine needles, and wheat straw significantly inhibited germination compared to the control. The treatments of importance compared to the control (100% germination), ranged from 67% for white oak sawdust to 1.9% for red maple leaves. All treatments significantly inhibited germination compared to no mulch. The no mulch treatment and pea gravel occurred first and second respectively on the table. Both treatments significantly contained more morningglory than most of the other treatments. These two treatments were predicted to occur at the top of the tables since they did not contain any allelochemicals.

Among the wood products eastern red cedar wood chips significantly inhibited germination compared to the other five. In addition, eastern red cedar wood chips significantly inhibited germination compared to no mulch, old white pine needles, wheat straw, johnsongrass, and fresh white pine needles. White oak sawdust, white oak bark, black walnut wood shavings, red oak bark, and red oak sawdust significantly inhibited germination compared to no mulch.

Table 27. The mean number of large crabgrass in each treatment for the greenhouse mulch layer experiment, experiment 3.

Mulch Treatment	Mean Number of Weeds[1]	
	Large Crabgrass	
No mulch	20.4	a
Pea Gravel (control)	10.4	b
Old White Pine needles	7.6	bc
Wheat straw	7.4	bc
White Oak sawdust	7.0	cd
White Oak bark	6.0	cde
Johnsongrass	5.8	cde
Black Walnut wood shavings	5.4	cde
Fresh White Pine needles	5.0	cdef
Red Oak bark	4.8	cdef
Red Oak sawdust	4.8	cdef
Black Cherry leaves	4.0	cdefg
Eastern Red Cedar foliage	3.6	defgh
Alfalfa	3.4	defgh
Black Walnut leaves	3.0	efgh
Hackberry leaves	2.6	efgh
Eastern Hemlock foliage	2.4	efgh
Sassafras leaves	1.4	fgh
Eastern Red Cedar wood chips	0.4	gh
Red Maple leaves	0.2	h

[1]Means followed by the same letter are not significantly different at the 5% level of probability according to Duncan's multiple range test.

Among the foliage treatments, red maple leaves significantly inhibited germination compared to old white pine needles, fresh white pine needles, and black cherry leaves. Sassafras leaves, eastern hemlock foliage, hackberry leaves, black walnut leaves, and eastern red cedar foliage significantly inhibited germination compared to old white pine needles. In addition, red maple leaves significantly inhibited germination compared to no mulch, wheat straw, white oak sawdust, white oak bark, johnsongrass, black walnut wood shavings, red oak bark, and red oak sawdust. Sassafras leaves significantly inhibited germination compared to no mulch, wheat straw, white oak sawdust, white oak bark, johnsongrass, and black walnut wood shavings. Black walnut leaves, hackberry leaves, and eastern hemlock foliage significantly inhibited germination compared to no mulch, wheat straw and white oak sawdust. Eastern red cedar foliage significantly inhibited germination compared to no mulch and wheat straw. Black cherry leaves, fresh white pine needles, and old white pine needles significantly inhibited germination compared to no mulch.

Among the straw and herbaceous plant mulches, alfalfa significantly inhibited germination compared to wheat straw. In addition, alfalfa significantly inhibited germination compared to no mulch and old white pine needles. Johnsongrass and wheat straw significantly inhibited germination compared to no mulch.

Greenhouse conditions definitely enhanced the effects of the mulches. All significantly inhibited germination compared to no mulch and most of the mulches significantly inhibited germination compared to the control.

Pigweed (Table 28). Eleven of the treatments significantly inhibited germination compared to the control. They were eastern red cedar wood chips, red maple leaves, sassafras leaves, black walnut wood shavings, black cherry leaves, eastern hemlock foliage, fresh white pine needles, eastern red cedar foliage, hackberry leaves, black walnut leaves, and white oak bark. The treatments of importance compared to the control (100% germination), ranged from 59% for white oak bark to 0% for eastern red cedar wood chips.

Among the wood products, eastern red cedar wood chips and black walnut wood shavings significantly inhibited germination compared to red oak bark, white oak sawdust, red oak sawdust, and white oak bark. White oak bark significantly inhibited germination compared to red oak bark and white oak sawdust. In addition, eastern red cedar wood chips significantly inhibited germination compared to old white pine needles, johnsongrass, wheat straw, no mulch, alfalfa, black walnut leaves, hackberry leaves,

Table 28. The mean number of pigweed in each treatment for the greenhouse mulch layer experiment, experiment 3.

Mulch Treatment	Mean Number of Weeds[1]
	Pigweed
Old White Pine needles	31.0 a
Pea Gravel (control)	28.6 ab
Johnsongrass	27.4 ab
Red Oak bark	27.2 ab
White Oak sawdust	26.0 ab
Wheat straw	24.8 abc
No mulch	24.6 abc
Red Oak sawdust	24.2 abc
Alfalfa	20.4 bcd
White Oak bark	17.0 cde
Black Walnut leaves	14.6 de
Hackberry leaves	13.4 de
Eastern Red Cedar foliage	12.2 de
Fresh White Pine needles	10.0 ef
Eastern Hemlock foliage	9.4 ef
Black Cherry leaves	8.8 ef
Black Walnut wood shavings	3.2 fg
Sassafras leaves	3.2 fg
Red Maple leaves	0.6 g
Eastern Red Cedar wood chips	0.0 g

[1]Means followed by the same letter are not significantly different at the 5% level of probability according to Duncan`s multiple range test.

eastern red cedar foliage, eastern hemlock foliage, and black cherry leaves. Black walnut wood shavings significantly inhibited germination compared to old white pine needles, johnsongrass, wheat straw, no mulch, alfalfa, black walnut leaves, hackberry leaves, and eastern red cedar foliage. White oak bark significantly inhibited germination compared to old white pine needles and johnsongrass.

All of the foliage treatments significantly inhibited pigweed compared to old white pine needles. Red maple leaves significantly inhibited germination compared to the other foliage treatments except sassafras leaves. Sassafras leaves significantly inhibited germination compared to black walnut leaves, hackberry leaves, and eastern red cedar foliage.

Alfalfa significantly inhibited germination compared to old white pine needles.

The greenhouse conditions enhanced the effects of most of the mulches on pigweed germination.

Overall Comparison (Tables 26-p.70, 27, and 28). Eight of the treatments, red maple leaves, sassafras leaves, eastern hemlock foliage, hackberry leaves, eastern red cedar foliage, black cherry leaves, fresh white pine needles, and black walnut wood shavings were common for significantly inhibiting germination of all three weeds compared to the control. All the treatments that significantly inhibited pigweed also significantly inhibited crabgrass. Also, all the treatments significant for morningglory were significant for crabgrass except old white pine needles and no mulch. In other words, more treatments significantly inhibited crabgrass suggesting that crabgrass is sensitive to a layer of mulch and/or a variety allelochemicals under greenhouse conditions.

Comparison of Experiment 2 and 3

Twenty of the 24 treatments in experiment 2 were also tested in experiment 3. Excluded from experiment 3 were pokeweed, pigweed, oat straw, and sugar maple sawdust.

Morningglory (Tables 19-p.48 and 26-p.70). Eight treatments were common for significantly inhibiting morningglory compared to the control. These were eastern hemlock foliage, black walnut wood shavings, no mulch, sassafras leaves, alfalfa, red maple leaves, fresh white pine needles, and eastern red cedar foliage.

Large Crabgrass (Tables 20-p.52 and 27-p.73). None of the treatments were common for significantly inhibiting germination of crabgrass compared to the control in both experiments, since none were significant in experiment 2.

Pigweed (Tables 21-p.54 and 28). Black walnut wood shavings and white oak bark were common for significantly inhibiting pigweed compared to the control in both experiments.

Overall Comparison (Tables 19-p.48, 20-p.52, 21-p.54, 26-p.70, 27, and 28). None of the treatments in experiment 2 significantly inhibited large crabgrass compared to the control. Therefore, black walnut wood shavings was the only treatment that significantly inhibited germination compared to the control for all three weeds in experiment 3, and for morningglory and pigweed in experiment 2.

White oak bark and black walnut leaves were common for significantly inhibiting germination except in experiment 3 for morningglory. Thus the greenhouse conditions provided characteristics that did not favor inhibition of morningglory.

Alfalfa significantly inhibited germination except in experiment 2 for pigweed. Thus the overwintering conditions did not favor inhibition of pigweed by alfalfa.

Eastern hemlock foliage significantly inhibited all three weeds in experiment 3, and morningglory in experiment 2.

Comparison of Experiment 1 and 3

There were nine treatments that were tested in both experiment 1 and 3, which were used for this comparison. These were pea gravel, no mulch, red oak bark, red oak sawdust, white oak bark, white oak sawdust, eastern red cedar wood chips, wheat straw, and black walnut leaves.

Morningglory (Tables 10-p.34 and 26-p.70). None of the nine treatments significantly inhibited morningglory compared to the control in both experiments, since none were significant in experiment 3. However, for experiment 1 black walnut leaves and wheat straw significantly inhibited morningglory compared to the control. It was theorized that the differences in environmental conditions and/or the differences in arrangement according to Duncan's multiple range test due to the differences in the types of treatments tested in each experiment caused different treatments to be significant.

Large Crabgrass (Tables 11-p.36 and 27-p.73). Eastern red cedar wood chips significantly inhibited crabgrass compared to the control in both experiments.

Pigweed (Tables 12-p.38 and 28). Eastern red cedar wood chips significantly inhibited pigweed germination compared to the control in both experiments.

Overall Comparison (Tables 10-p.34, 11-p.36, 12-p.38, 26-p.70, 27-p.73, and 28). None of the treatments were common for significantly inhibiting germination of all three weeds compared to the control. However, eastern red cedar wood chips significantly inhibited crabgrass and pigweed.

Wheat straw significantly inhibited germination in experiment 1 but did not in experiment 3. Thus, the differences in environmental conditions definitely affected the performance of wheat straw.

Experiment 4-Greenhouse Mulch Leachate Study

Leachate Analysis (Table 29)

The soluble salt readings for the first watering of leachates obtained from the mulches ranged from 3.2 mmhos (alfalfa) to 0.0 mmhos (no mulch or distilled water). The soluble salt concentration decreased as the number of mulch soakings increased. This was represented by three of the seven leachate series used for watering the weed seeds.

The average pH of the leachates ranged from 6.2 (no mulch or distilled water) to 4.0 (eastern hemlock foliage and red oak bark), approximately a 100 fold difference.

The correlation of soluble salts and ph between

Table 29. Soluble salt readings for leachate watering numbers 1, 4, and 7 and the mean pH reading for each leachate treatment in the greenhouse mulch leachate experiment, experiment 4.

Mulch Leachate	Watering Number	SS (mmhos)	Mean pH
Alfalfa	1	3.20	5.0
	4	.15	
	7	.10	
Hackberry leaves	1	2.25	6.0
	4	.36	
	7	.20	
Red Maple leaves	1	1.90	4.5
	4	.12	
	7	0.00	
Sassafras leaves	1	1.75	5.2
	4	.13	
	7	0.00	
Black Cherry leaves	1	1.37	5.0
	4	.07	
	7	0.00	
Black Walnut leaves	1	1.25	5.2
	4	.09	
	7	0.00	
Johnsongrass	1	1.13	4.9
	4	.16	
	7	0.00	
Eastern Hemlock foliage	1	.95	4.0
	4	.54	
	7	.12	
Eastern Red Cedar foliage	1	.83	4.8
	4	.22	
	7	.09	

Table 29 (continued)

Mulch Leachate	Watering Number	SS (mmhos)	Mean pH
Wheat straw	1	.77	5.3
	4	.05	
	7	0.00	
White Oak bark	1	.53	5.1
	4	.19	
	7	.12	
Red Oak bark	1	.50	4.5
	4	.15	
	7	0.00	
Eastern Red Cedar wood chips	1	.30	5.0
	4	.05	
	7	0.00	
White Oak sawdust	1	.29	4.3
	4	.08	
	7	0.00	
Red Oak sawdust	1	.28	4.0
	4	.07	
	7	0.00	
Black Walnut wood shavings	1	.14	4.7
	4	.03	
	7	0.00	
Old White Pine needles	1	.14	5.0
	4	.07	
	7	0.00	

Table 29 (continued)

Mulch Leachate	Watering Number	SS (mmhos)	Mean pH
Fresh White Pine needles	1	.14	4.6
	4	.14	
	7	0.00	
Pea Gravel	1	.10	5.8
	4	.03	
	7	0.00	
No mulch (distilled water)	1	0.00	6.2
	4	0.00	
	7	0.00	

germination was not significant since the correlation coefficient was not .80 or greater. The greatest correlation between soluble salts and germination was a negative .58 for morningglory. The greatest correlation between ph and germination was a positive .47 for large crabgrass.

Weed Analysis

Morningglory (Table 30). Nine leachate treatments significantly inhibited germination compared to the controls. These were red maple leaves, sassafras leaves, eastern hemlock foliage, white oak bark, eastern red cedar foliage, hackberry leaves, black walnut leaves, black cherry leaves, and alfalfa. The leachates of importance compared to the controls (100% germination), ranged from 63% for alfalfa to 5% for red maple leaves. The controls occurred together and toward the top of the table as was predicted since they contained no allelochemicals.

Among the wood products, white oak bark significantly inhibited morningglory compared to the other remaining wood products. Red oak bark significantly inhibited germination compared to red oak sawdust and black walnut wood shavings. Eastern red cedar wood chips inhibited germination compared to red oak sawdust. In addition, white oak bark significantly inhibited germination compared to johnsongrass.

Table 30. The mean number of morningglory in each leachate treatment for the greenhouse mulch leachate experiment, experiment 4.

Mulch Leachate	Mean Number of Weeds[1] Morningglory
Red Oak sawdust	24.6 a
Black Walnut wood shavings	23.2 ab
Johnsongrass	23.0 ab
No mulch (control)	22.8 ab
Pea Gravel (control)	19.6 abc
Old White Pine needles	19.4 abc
White Oak sawdust	18.4 abcd
Eastern Red Cedar wood chips	17.8 bcde
Red Oak bark	16.2 cde
Fresh White Pine needles	15.2 cdef
Wheat straw	13.8 cdef
Alfalfa	12.4 defg
Black Cherry leaves	12.0 defgh
Black Walnut leaves	11.4 efgh
Hackberry leaves	9.6 fgh
Eastern Red Cedar foliage	9.4 fgh
White Oak bark	6.2 ghi
Eastern Hemlock foliage	5.8 hi
Sassfras leaves	1.8 i
Red Maple leaves	1.0 i

[1]Means followed by the same letter are not significantly different at the 5% level of probability according to Duncan`s multiple range test.

All foliage treatments except fresh white pine needles significantly inhibited morningglory compared to old white pine needles. Red maple leaves and sassafras leaves significantly inhibited germination compared to fresh white pine needles, black cherry leaves, black walnut leaves, and hackberry leaves. Eastern red cedar foliage and eastern hemlock foliage significantly inhibited germination compared to fresh white pine needles. In addition, red maple leaves, sassafras leaves, and eastern hemlock foliage significantly inhibited germination compared to red oak sawdust, black walnut wood shavings, johnsongrass, white oak sawdust, eastern red cedar wood chips, red oak bark, wheat straw, and alfalfa. Eastern red cedar foliage and hackberry leaves significantly inhibited germination compared to red oak sawdust, black walnut wood shavings, johnsongrass, white oak sawdust, eastern red cedar wood chips, and red oak bark. Black walnut leaves significantly inhibited germination compared to red oak sawdust, black walnut wood shavings, johnsongrass, and white oak sawdust. Black cherry leaves and fresh white pine needles significantly inhibited germination compared to red oak sawdust, black walnut wood shavings, and johnsongrass.

Among the straw and herbaceous plant leachates, alfalfa and wheat straw significantly inhibited germination of morningglory compared to johnsongrass. Alfalfa also significantly inhibited germination compared to red oak sawdust, black walnut wood shavings, and old white pine needles. Wheat straw significantly inhibited germination compared to red oak sawdust and black walnut wood shavings.

Large Crabgrass (Table 31). Twelve of the leachate treatments significantly inhibited germination compared to the controls. These were eastern hemlock foliage, red maple leaves, eastern red cedar foliage, sassafras leaves, white oak bark, red oak bark, hackberry leaves, black walnut leaves, black walnut wood shavings, black cherry leaves, white oak sawdust, and johnsongrass. The leachates of importance compared to the controls (100% germination), ranged from 70% for johnsongrass to 0.0% for eastern hemlock foliage.

Among the wood products, white oak bark significantly inhibited crabgrass germination compared to eastern red cedar wood chips and red oak sawdust. White oak bark also significantly inhibited germination compared to old white pine needles, wheat straw, fresh white pine needles, alfalfa, and johnsongrass. Red oak bark significantly inhibited germination compared to old white pine needles, wheat straw, fresh white pine needles, and alfalfa. Black walnut wood shavings, white oak sawdust, red oak sawdust, and eastern red cedar wood chips significantly inhibited

Table 31. The mean number of large crabgrass in each leachate treatment for the greenhouse mulch leachate experiment, experiment 4.

Mulch Leachate	Mean Number of Weeds[1] Large Crabgrass
Old White Pine needles	17.2 a
No mulch (control)	16.2 ab
Wheat straw	15.8 ab
Pea Gravel (control)	15.4 abc
Fresh White Pine needles	12.8 bcd
Alfalfa	12.6 bcde
Eastern Red Cedar wood chips	11.4 cdef
Red Oak sawdust	11.4 cdef
Johnsongrass	10.8 def
White Oak sawdust	10.0 defg
Black Cherry leaves	8.8 defgh
Black Walnut wood shavings	8.8 defgh
Black Walnut leaves	8.4 efghi
Hackberry leaves	8.4 efghi
Red Oak bark	7.6 fghi
White Oak bark	6.4 ghi
Sassafras leaves	5.8 hij
Eastern Red Cedar foliage	4.4 ij
Red Maple leaves	2.4 jk
Eastern Hemlock foliage	0.0 k

[1]Means followed by the same letter are not significantly different at the 5% level of probability according to Duncan`s multiple range test.

germination compared to old white pine needles and wheat straw.

Among the foliage treatments, all the leachates significantly inhibited crabgrass germination compared to old white pine needles. All the foliage leachate treatments except the pine needles occurred below midway in the table. Eastern hemlock foliage significantly inhibited germination compared to fresh white pine needles, black cherry leaves, black walnut leaves, hackberry leaves, sassafras leaves, and eastern red cedar foliage. Red maple leaves significantly inhibited germination compared to fresh white pine needles, black cherry leaves, black walnut leaves, and hackberry leaves. Eastern red cedar foliage significantly inhibited germination compared to fresh white pine needles and black cherry leaves. Sassafras leaves, hackberry leaves, and black walnut leaves significantly inhibited germination compared to fresh white pine needles. In addition, eastern hemlock foliage and red maple leaves significantly inhibited germination compared to all remaining treatments except sassafras leaves and eastern red cedar foliage. Eastern red cedar foliage significantly inhibited germination compared to wheat straw, alfalfa, eastern red cedar wood chips, red oak sawdust, johnsongrass, white oak sawdust, and black walnut wood shavings. Sassafras leaves significantly inhibited germination compared to wheat straw, alfalfa, eastern red cedar wood chips, red oak sawdust, johnsongrass, and white oak sawdust. Hackberry leaves, black walnut leaves, and black cherry leaves significantly inhibited germination compared to wheat straw.

Among the straw and herbaceous plant leachates, johnsongrass significantly inhibited crabgrass compared to wheat straw. Johsongrass and alfalfa significantly inhibited germination compared to old white pine needles.

Pigweed (Table 32). Ten of the leachates significantly inhibited pigweed germination compared to the controls. These were red maple leaves, eastern red cedar foliage, eastern hemlock foliage, eastern red cedar wood chips, sassafras leaves, black walnut wood shavings, black walnut leaves, red oak bark, fresh white pine needles, and red oak sawdust. The leachates of importance compared to the controls (100% germination), ranged from 78% for red oak bark to 0.0% for red maple leaves.

Among the wood products, eastern red cedar wood chips and black walnut wood shavings significantly inhibited germination compared to white oak bark, white oak sawdust, red oak sawdust, and red oak bark. Also eastern red cedar wood chips and black walnut wood shavings significantly inhibited germination compared to wheat straw, alfalfa, black cherry leaves, old white pine needles, johnsongrass,

Table 32. The mean number of pigweed in each leachate treatment for the greenhouse mulch leachate experiment, experiment 4.

Mulch Leachate	Mean Number of Weeds[1] Pigweed
Pea Gravel (control)	32.8 a
No mulch (control)	29.4 ab
Wheat straw	29.2 abc
Alfalfa	28.0 abc
Black Cherry leaves	26.8 abc
Old White Pine needles	26.8 abc
Johnsongrass	26.0 bc
White Oak bark	25.2 bcd
Hackberry leaves	25.0 bcd
White Oak sawdust	23.6 bcd
Red Oak sawdust	23.0 cd
Fresh White Pine needles	19.4 de
Red Oak bark	19.4 de
Black Walnut leaves	14.0 e
Black Walnut wood shavings	8.0 f
Sassafras leaves	6.8 fg
Eastern Red Cedar wood chips	5.6 fgh
Eastern Hemlock foliage	2.0 gh
Eastern Red Cedar foliage	1.0 h
Red Maple leaves	0.0 h

[1]Means followed by the same letter are not significantly different at the 5% level of probability according to Duncan`s multiple range test.

hackberry leaves, fresh white pine needles, and black walnut leaves. Red oak bark significantly inhibited germination compared to wheat straw, alfalfa, black cherry leaves, old white pine needles, and johnsongrass.

Among the foliage treatments, red maple leaves and eastern red cedar foliage significantly inhibited pigweed compared to black cherry leaves, old white pine needles, hackberry leaves, fresh white pine needles, black walnut leaves, and sassafras leaves. Eastern hemlock foliage and sassafras leaves significantly inhibited germination compared to black cherry leaves, old white pine needles, hackberry leaves, fresh white pine needles, and black walnut leaves. Black walnut leaves significantly inhibited germination compared to black cherry leaves, old white pine needles, and hackberry leaves. Fresh white pine needles significantly inhibited germination compared to black cherry leaves and old white pine needles. In addition, red maple leaves, eastern red cedar foliage, and eastern hemlock foliage significantly inhibited germination compared to all remaining treatments except for eastern red cedar wood chips. Sassafras leaves significantly inhibited germination compared to wheat straw, alfalfa, johnsongrass, white oak bark, white oak sawdust, red oak sawdust, and red oak bark. Black walnut leaves significantly inhibited germination compared to wheat straw, alfalfa, johnsongrass, white oak bark, white oak sawdust, and red oak sawdust. Fresh white pine needles significantly inhibited germination compared to wheat straw, alfalfa, and johnsongrass.

None of the straw and herbaceous plant leachates significantly inhibited pigweed compared to each other or to other treatments.

Overall Comparison (Tables 30-p.85, 31, and 32). Five of the leachates, red maple leaves, eastern red cedar foliage, eastern hemlock foliage, sassafras leaves, and black walnut leaves significantly inhibited germination compared to the controls for all three weeds.

Comparison of Experiment 3 and 4

Morningglory (Tables 26-p.70 and 30-p.86). Both experiments had seven treatments in common that significantly inhibited morningglory compared to the control. These were red maple leaves, sassafras leaves, eastern hemlock foliage, eastern red cedar foliage, hackberry leaves, black cherry leaves and alfalfa.

Large Crabgrass (Tables 27-p.73 and 31-p.89). Both experiments had twelve treatments in common that significantly inhibited crabgrass compared to the control.

These were eastern hemlock foliage, red maple leaves, eastern red cedar foliage, sassafras leaves, white oak bark, red oak bark, hackberry leaves, black walnut leaves, black walnut wood shavings, black cherry leaves, white oak sawdust, and johnsongrass.

Pigweed (Tables 28-p.76 and 32). Both of the experiments had eight treatments in common that significantly inhibited pigweed compared to the control. These were eastern red cedar wood chips, red maple leaves, sassafras leaves, black walnut wood shavings, eastern hemlock foliage, fresh white pine needles, eastern red cedar foliage, and black walnut leaves.

Overall Comparison (Tables 26-p.70, 27-p.73, 28-p.76, 30-p.86, 31-p.89, and 32). Four treatments, red maple leaves, eastern hemlock foliage, sassafras leaves, and eastern red cedar foliage significantly inhibited germination compared to the control for all three weeds. In addition, black walnut leaves significantly inhibited germination compared to the control except in experiment 3 for morningglory.

Experiment 4-Petri Dish
Mulch Leachate Study

Weed Analysis

Morningglory (Table 33). Only two leachate treatments, black walnut leaves (83%) and red oak bark (86%) significantly inhibited morningglory compared to the controls (100% germination). Black walnut leaves also significantly inhibited germination compared to the other treatments except red oak bark, eastern red cedar wood chips, sassafras leaves, hackberry leaves, and white oak bark. Red oak bark significantly inhibited germination compared to eastern red cedar foliage, johnsongrass, alfalfa, and fresh white pine needles.

Large Crabgrass (Table 34). Six of the leachates, red maple leaves, sassafras leaves, hackberry leaves, black walnut leaves, alfalfa, and eastern red cedar foliage significantly inhibited crabgrass compared to the controls. The leachates of importance compared to the controls (100% germination), ranged from 7% for red maple leaves to 69% for eastern red cedar foliage.

None of the wood products significantly inhibited crabgrass compared to each other or to other leachates.

Among the foliage leachates, red maple leaves and sassafras leaves significantly inhibited germination compared to the remaining foliage treatments. Hackberry

Table 33. The mean number of morningglory in each leachate treatment for the petri dish leachate experiment, experiment 4.

Mulch Leachate	Mean Number of Weeds[1] Morningglory
Pea Gravel (control)	32.6 a
Easter Red Cedar foliage	32.4 a
Johnsongrass	32.2 a
Alfalfa	32.2 a
No mulch (control)	31.8 a
Fresh White Pine needles	31.2 a
Black Walnut wood shavings	31.0 ab
Eastern Hemlock foliage	31.0 ab
Wheat straw	30.8 ab
Black Cherry leaves	30.6 ab
White Oak sawdust	30.4 ab
Red Maple leaves	30.4 ab
Red Oak sawdust	30.4 ab
Old White Pine needles	30.2 ab
White Oak bark	29.8 abc
Hackberry leaves	29.8 abc
Sassfras leaves	29.6 abc
Eastern Red Cedar wood chips	29.6 abc
Red Oak bark	27.6 bc
Black Walnut leaves	26.8 c

[1]Means followed by the same letter are not significantly different at the 5% level of probability according to Duncan`s multiple range test.

Table 34. The mean number of large crabgrass in each leachate treatment for the petri dish leachate experiment, experiment 4.

Mulch Leachate	Mean Number of Weeds[1] Large Crabgrass
Red Oak sawdust	27.2 a
White Oak sawdust	26.8 ab
No mulch (control)	26.6 ab
Johnsongrass	26.4 ab
Black Walnut wood shavings	26.2 ab
Red Oak bark	25.8 ab
Wheat straw	25.6 ab
Black Cherry leaves	25.4 ab
Pea Gravel (control)	25.2 ab
Eastern Red Cedar wood chips	24.6 ab
Eastern Hemlock foliage	24.6 ab
Fresh White Pine needles	24.2 ab
White Oak bark	21.4 abc
Old White Pine needles	20.2 bc
Eastern Red Cedar foliage	18.0 cd
Alfalfa	17.6 cd
Black Walnut leaves	15.8 cd
Hackberry leaves	13.6 d
Sassafras leaves	8.0 e
Red Maple leaves	1.8 f

[1]Means followed by the same letter are not significantly different at the 5% level of probability according to Duncan`s multiple range test.

leaves significantly inhibited germination compared to black cherry leaves, eastern hemlock foliage, fresh white pine needles, and old white pine needles. Black walnut leaves and eastern red cedar foliage significantly inhibited germination compared to black cherry leaves, eastern hemlock foliage, and fresh white pine needles. In addition, red maple leaves and sassafras leaves significantly inhibited germination compared to all other treatments. Hackberry leaves significantly inhibited germination compared to red oak sawdust, white oak sawdust, johnsongrass, black walnut wood shavings, red oak bark, wheat straw, eastern red cedar wood chips, and white oak bark. Eastern red cedar foliage and black walnut leaves significantly inhibited germination compared to red oak sawdust, white oak sawdust, johnsongrass, black walnut wood shavings, red oak bark, wheat straw, and eastern red cedar wood chips. Old white pine needles significantly inhibited germination compared to red oak sawdust.

Among the straw and herbaceous plant leachates, alfalfa significantly inhibited germination compared to johnsongrass. Alfalfa also significantly inhibited germination compared to red oak sawdust, white oak sawdust, black walnut wood shavings, red oak bark, black cherry leaves, eastern red cedar wood chips, eastern hemlock foliage, and fresh white pine needles.

Pigweed (Tables 35). Five of the treatments, wheat straw, alfalfa, hackberry leaves, jonhsongrass, and sassafras leaves significantly inhibited germination compared to the controls. The leachates of importance compared to the controls (100% germination), ranged from 76% for wheat straw to 84% for sassafrass leaves.

None of the wood products significantly inhibited pigweed compared to each other and other leachates.

Among the foliage treatments hackberry leaves significantly inhibited germination compared to fresh white pine needles, red maple leaves, old white pine needles, and black walnut leaves. Sassafras leaves, black cherry leaves, eastern hemlock foliage, and eastern red cedar foliage significantly inhibited germination compared to fresh white pine needles and red maple leaves. In addition, hackberry leaves and sassafrass leaves significantly inhibited germination compared to red oak sawdust, eastern red cedar wood chips, red oak bark, black walnut wood shavings, white oak sawdust, and white oak bark. Eastern hemlock foliage and black cherry leaves significantly inhibited germination compared to red oak sawdust, eastern redar wood chips, red oak bark, black walnut wood shavings, and white oak sawdust. Eastern red cedar foliage and black walnut leaves significantly inhibited germination compared to red oak sawdust and eastern red cedar wood chips. Old white pine

Table 35. The mean number of pigweed in each leachate treatment for the petri dish leachate experiment, experiment 4.

Mulch Leachate	Mean Number of Weeds[1] Pigweed
Red Oak sawdust	66.2 a
Eastern Red Cedar wood chips	64.2 ab
Red Oak bark	62.0 abc
Fresh White Pine needles	61.0 abc
Black Walnut wood shavings	61.0 abc
Red Maple leaves	60.8 abc
No mulch (control)	60.8 abc
White Oak sawdust	60.6 abc
White Oak bark	59.4 abcd
Pea Gravel (control)	59.0 abcd
Old White Pine needles	57.6 bcde
Black Walnut leaves	55.6 cde
Eastern Red Cedar foliage	54.8 cdef
Eastern Hemlock foliage	53.0 defg
Black Cherry leaves	52.2 defg
Sassafras leaves	50.4 efg
Johnsongrass	48.0 fg
Hackberry leaves	47.6 fg
Alfalfa	47.4 fg
Wheat straw	45.8 g

[1]Means followed by the same letter are not significantly different at the 5% level of probability according to Duncan`s multiple range test.

needles significantly inhibited germination compared to red oak sawdust.

Wheat straw significantly inhibited germination compared to red oak sawdust, eastern red cedar wood chips, red oak bark, fresh white pine needles, black walnut wood shavings, red maple leaves, white oak sawdust, white oak bark, old white pine needles, black walnut leaves, and eastern red cedar foliage. Alfalfa and johnsongrass significantly inhibited germination compared to red oak sawdust, eastern red cedar wood chips, red oak bark, fresh white pine needles, black walnut wood shavings, red maple leaves, white oak sawdust, white oak bark, old white pine needles, and black walnut leaves.

Overall Comparison (Tables 33, 34, and 35). None of the treatments were common for significantly inhibiting germination of all three weeds compared to the controls. However, black walnut leaves significantly inhibited germination of morningglory and crabgrass. Sassafras leaves, hackberry leaves, and alfalfa significantly inhibited germination of crabgrass and pigweed. However, the germination percentages of the significant leachates were very high. This experiment was done under more controlled conditions compared to the other experiments, which allowed treatment response to be significant even when the total reduction in germination was not great.

Comparison of Experiment 4 (greenhouse and petri dish)

<u>Morningglory (Tables 30-p.86 and 33-p.97).</u> Black walnut leaves was the only leachate in common that significantly inhibited morningglory compared to the controls.

<u>Large Crabgrass (Tables 31-p.89 and 34).</u> Five of the leachates, red maple leaves, sassafras leaves, hackberry leaves, black walnut leaves, and eastern red cedar wood chips significantly inhibited crabgrass compared to the controls in both experiments.

<u>Pigweed (Tables 32-p.92 and 35).</u> Sassafras leaves was the only leachate common for significantly inhibiting pigweed germination compared to the controls in both experiments.

<u>Overall Comparison (Tables 30-p.86, 31-p.89, 32-p.92, 33-p.97, 34, and 35).</u> None of the leachates were common for inhibiting germination compared to the controls for all three weeds. However, sassafras leaves significantly inhibited germination compared to the controls except for morningglory in the petri dishes. Black walnut leaves significantly inhibited germination compared to the controls except for pigweed in the petri dishes.

Comparison of Experiment 3 and 4 - Petri Dish

Morningglory (Tables 26-p.70 and 33-p.97). None of the treatments were common for significantly inhibiting germination of morningglory compared to the control for both experiments.

Large Crabgrass (Tables 27-p.73 and 34-p.98). Red maple leaves, sassafras leaves, hackberry leaves, black walnut leaves, eastern red cedar foliage, and alfalfa all significantly inhibited germination of crabgrass compared to the control in both experiments.

Pigweed (Tables 28-p.76 and 35). Sassafras leaves and hackberry leaves significantly inhibited germination of pigweed compared to the control in both experiments.

Overall Comparison (Tables 26-p.70, 27-p.73, 28-p.76, 33-p.96, 34-p.98, and 35). None of the treatments were common for significantly inhibiting germination compared to the control in both experiments for all three weeds. However, sassafras leaves and hackberry leaves significantly inhibited germination compared to the control except for morningglory in experiment 4 - petri dish.

Comparison of Experiment 2, 3, and 4 - Greenhouse

Morningglory (Tables 19-p.48, 26-p.70, and 30-p.86). Red maple leaves, sassafras leaves, eastern hemlock foliage, eastern red cedar foliage, and alfalfa significantly inhibited morningglory germination compared to the control in all three experiments.

Large Crabgrass (Tables 20-p.52, 27-p.73, and 31-p.89). None of the treatments were common for significantly inhibiting crabgrass for all three experiments.

Pigweed (Tables 21-p.54, 28-p.76, and 32-p.92). Black walnut wood shavings was common for significantly inhibiting germination of pigweed for all three experiments.

Overall Comparison (Tables 19-p.48, 20-p.52, 21-p.54, 26-p.70, 27-p.73, 28-p.76, 30-p.86, 31-p.89, 32-p.92). None of the treatments were common for significantly inhibiting germination compared to the control even with the exclusion of experiment 2 for crabgrass. However, black walnut wood shavings was common for significantly inhibiting germination except in morningglory. Eastern red cedar foliage, eastern hemlock foliage, sassafras leaves, and red maple leaves significantly inhibited germination except in experiment 2 for pigweed.

V. SUMMARY AND CONCLUSIONS

According to Rice (1974), R.H. Whittaker defines allelochemicals as chemicals released from higher plants (directly or by way of decay processes) that inhibit the germination, growth, or occurrence of other plants. The objectives for this research were to determine the allelopathic effect of mulches on: (1) the germination of selected weed seeds and (2) the growth of selected ornamental plants.

Experiments were conducted in the field and greenhouse using pea gravel and/or no mulch as the controls. The allelopathic effects of the mulches on the germination of morningglory, large crabgrass, and pigweed seeds were evaluated for all the experiments. The field experiments also included an evaluation of the allelopathic effects of the mulches on the growth of ornamental plants: (experiment 1) - sunflower, marigold, willow, cotoneaster, crapemyrtle, and red maple; (experiment 2) - cotoneaster, dogwood, euonymus, and holly.

Experiment 1 was installed in the field during the summer season of 1987 and included twenty mulch treatments. A great deal of variability existed among the replications (rows of plots), possibly due to the uneven distribution of weed seeds and irrigation.

A few mulch treatments were significant for inhibiting germination compared to the control (Table 36). The mulches that inhibited germination most were:

black walnut leaves - 51% inhibition of morningglory
barley straw - 89% inhibition of large crabgrass
rye straw - 100% inhibition of pigweed

Also eastern red cedar wood chips, barley straw, rye straw, and wheat straw significantly inhibited germination of two types of weeds.

Wheat straw significantly inhibited the growth of red maple (.5 grams) compared to pea gravel (3 grams). None of the other ornamentals were significantly inhibited by any of the mulches.

Experiment 2 was installed in the field during the winter season of 1987 and included eleven of the twenty mulch treatments tested in experiment 1 plus thirteen additional mulches. A predetermined amount of weed seeds were scattered by hand over each plot and the site was irrigated only by natural rainfall. This was done in an attempt to eliminate the variability that occurred in experiment 1. Also the ornamental plants were more carefully selected for uniformity.

The number of mulches that significantly inhibited germination compared to the control varied between weed types (Table 36). Eighteen of the twenty-four treatments significantly inhibited morningglory, none inhibited large

Table 36. List of mulch treatments tested and the weeds significantly inhibited in field experiments 1 and 2.

Mulch Treatment	Field Experiments[1] exp 1	Field Experiments[1] exp 2
Beech bark	x	
Beech sawdust	x	
Black walnut wood shavings		x M-84 P-97
Eastern red cedar wood chips	x C-87 P-98	x
Hickory bark	x	
Pine bark	x	
Pine sawdust	x	
Red oak bark	x	x M-70
Red oak sawdust	x	x M-56 P-89
Sugar maple bark	x	
Sugar maple sawdust	x	x M-42 P-97
White oak bark	x	x M-55 P-89
White oak sawdust	x	x M-45
Yellow poplar bark	x	
Yellow poplar sawdust	x	
Barley straw	x C-89 P-94	
Oat straw		x M-73
Rye straw	x C-86 P-100	
Wheat straw	x M-44 P-94	x M-86
Black cherry leaves		x
Black walnut leaves	x M-51	x M-49
Eastern hemlock foliage		x M-86
Eastern red cedar foliage		x M-41
Hackberry leaves		x
Red maple leaves		x M-49
Sassafras leaves		x M-56
White pine needles (fresh)		x M-45
White pine needles (old)		x

Table 36 (continued)

Mulch Treatment	Field Experiments[1] exp 1	exp 2
Alfalfa		x M-52
Johnsongrass		x M-79
Pigweed		x
Pokeweed		x M-56
No treatment	x	x M-69
Pea gravel (control)	x	x

[1]x designates the mulches were tested in the experiment, M = mulch is significant for inhibiting Morningglory, C = mulch is significant for inhibiting Crabgrass, P = mulch is significant for inhibiting Pigweed, the number = percent inhibition compared to the control-0%.

crabgrass, and four inhibited pigweed. The reason for these differences between weed types was unknown but it was speculated that a rapid drop in temperature after sowing affected the results, especially for morningglory. This however does not explain why treatments were significant. Due to the length of the experiment the allelochemicals may have already leached out of the mulch materials by the time the weed seeds germinated the following summer or may have affected the seeds before germination occurred, which may have been responsible for significantly inhibiting germination. Also, the relationship of weed seeds underneath a layer of mulch provides variables of its own. How does the layer of mulch effect the seeds as they overwinter?

Mulches that inhibited germination of the most seeds were (Table 36):

eastern hemlock foliage
wheat straw _ 86% inhibition of morningglory

sugar maple sawdust
black walnut wood shavings _ 97% inhibition of pigweed

Also, black walnut wood shavings, sugar maple sawdust, white oak bark, and red oak sawdust significantly inhibited the germination of morningglory and pigweed. Among the four ornamental plants tested, cotoneaster and euonymus were significantly inhibited by a few treatments. The no mulch treatment and alfalfa significantly inhibited cotoneaster whereas sugar maple sawdust, red oak sawdust, white oak bark, and wheat straw significantly inhibited euonymus.

Experiment 3 was installed in the greenhouse during the winter of 1987 and included twenty of the twenty-four treatments tested in experiment 1. A one inch layer of mulch was spread over a predetermined number of weed seeds which were sown on sand in pots. The weeds were watered regularly with a measured amount of distilled water. This experiment was done to reduce the variation of environmental conditions that occurred in the field experiments.

Mulch treatments that significantly inhibited germination did not vary much between weed types (Table 37). The mulches that inhibited germination the most were:

alfalfa	- 38% inhibition of morningglory
red maple leaves	- 98% inhibition of large crabgrass
eastern red cedar wood chips	- 100% inhibition of pigweed

In addition red maple leaves, sassafras leaves, eastern hemlock foliage, hackberry leaves, eastern red cedar foliage, black cherry leaves, fresh white pine needles, and black walnut wood shavings significantly inhibited germination of all three weeds. Eastern red cedar wood chips, black walnut leaves, and white oak bark significantly inhibited germination of large crabgrass and pigweed and alfalfa significantly inhibited morningglory and large crabgrass. Variation in treatments may have been

Table 37. List of mulch treatments tested and the weeds significantly inhibited in the greenhouse experiments 3 and 4.

Mulch Treatment	Greenhouse Experiments[1] exp 3	exp 4
Beech bark		
Beech sawdust		
Black walnut wood shavings	x M-17 C-48 P-89	x C-44 P-74
Eastern red cedar wood chips	x C-96 P-100	x P-82
Hickory bark		
Pine bark		
Pine sawdust		
Red oak bark	x C-54	x C-52 P-38
Red oak sawdust	x C-54	x P-26
Sugar maple bark		
Sugar maple sawdust		
White oak bark	x C-42 P-41	x M-71 C-60
White oak sawdust	x C-33	x C-37
Yellow poplar bark		
Yellow poplar sawdust		
Barley straw		
Oat straw		
Rye straw		
Wheat straw	x	x
Black cherry leaves	x M-29 C-62 P-69	x M-43 C-44
Black walnut leaves	x C-71 P-49	x M-46 C-47 P-55
Eastern hemlock foliage	x M-26 C-77 P-67	x M-73 C-100 P-94
Eastern red cedar foliage	x M-27 C-65 P-57	x M-56 C-72 P-97
Hackberry leaves	x M-20 C-75 P-53	x M-55 C-47
Red maple leaves	x M-28 C-98 P-98	x M-95 C-85 P-100
Sassafras leaves	x M-19 C-87 P-89	x M-92 C-63 P-78
White pine needles (fresh)	x M-19 C-52 P-65	x P-38
White pine needles (old)	x M-23	x

Table 37 (Continued)

Mulch Treatment	Greenhouse Experiments[1] exp 3	exp 4
Alfalfa	x M-38 C-67	x M-42
Johnsongrass	x C-44	x C-32
Pigweed		
Pokeweed		
No treatment	x M-69	x(control)
Pea gravel (control)	x	x

[1]x designates the mulches were tested in the experiment, M = mulch is significant for inhibiting Morningglory, C = mulch is significant for inhibiting Crabgrass, P = mulch is significant for inhibiting Pigweed, the number = percent inhibition compared to the control(s)-0%.

due to the size and physiological differences of the weed seeds.

Experiment 4 was installed in the greenhouse at the same time as experiment 3. It was arranged the same except that mulch leachates were used as treatments. Thus, leachates were also used to water the weed seeds. This experiment was done in an attempt to eliminate variables due to a layer of mulch, providing a better basis for concluding that allelochemicals were responsible for inhibiting germination.

The number of treatments significant for inhibiting germination did not vary much between weed types (Table 37). The leachate treatments that inhibited germination most were:

red maple leaves	-	95% inhibition of morningglory
		100% inhibition of pigweed
eastern hemlock foliage	-	100% inhibition of large crabgrass

Also eastern hemlock foliage, red maple leaves, eastern red cedar foliage, sassafras leaves, and black walnut leaves significantly inhibited germination of all three weeds. Black walnut wood shavings and red oak bark significantly inhibited large crabgrass and pigweed and white oak bark, hackberry leaves, and black cherry leaves significantly inhibited morningglory and large crabgrass. Variation in treatments may have been due to the size and germination capacity of the weed seeds.

Experiment 4 also included a second part in which leachate was poured into petri dishes containing the individual weed seeds and filter paper. Since this type of experiment was even more removed from reality than the greenhouse experiments, the results will not be referred to in this summary and conclusion. The experiment was done to satisfy scientific research techniques in that by eliminating all possible variables the cause of inhibition would be found.

Due to the similarity in growing conditions of experiments 3 and 4 and the difference of only one physical variable, the two experiments could logically be compared. Red maple leaves, eastern hemlock foliage, sassafras leaves, and eastern red cedar foliage were common for inhibiting germination of all three weeds in both experiments. Also, hackberry leaves, black cherry leaves, and alfalfa significantly inhibited morningglory, eastern red cedar wood chips, black walnut wood shavings, black walnut leaves, and fresh white pine needles were common for significantly inhibiting pigweed, and white oak bark, red oak bark, hackberry leaves, black walnut leaves, black walnut wood shavings, black cherry leaves, white oak sawdust, and johnsongrass were common for signifcantly inhibiting large crabgrass. Large crabgrass was affected by twice as many treatments as morningglory and pigweed.

Most importantly, in regard to the purpose of this research project, the comparison of these two experiments suggests that allelochemicals played a major role in inhibiting the weeds. Several of the mulch treatments were common for significantly inhibiting germination in both experiments even though experiment 4 had no layer of mulch over the weed seeds.

A comparison of experiment 1, 2, and 3 would not be as logical due to the the great differences in environmental conditions, but since they all involved the use of a layer of mulch over the weed seeds it was interesting to find similarities between the mulch treatments. The most obvious similarity was that eastern red cedar wood chips significantly inhibited large crabgrass and pigweed in experiment 1 and 3. This suggested that in the presence of warm temperatures and sufficient water eastern red cedar wood chips was most effective for inhibiting germination. A second similarity was that black walnut wood shavings and white oak bark significantly inhibited pigweed in experiment 2 and 3. This suggested that these two mulches were effective in inhibiting germination in the field and in the greenhouse. A third similarity was that black walnut leaves and wheat straw significantly inhibited morningglory in experiment 1 and 2. This suggested that the field conditions favored inhibition of germination. Fourthly eastern hemlock foliage, black walnut wood shavings, sassafras leaves, alfalfa, red maple leaves, fresh white pine needles, and eastern red cedar foliage significantly inhibited morningglory in experiment 2 and 3. This suggested that these mulches were effective in inhibiting germination in the field and in the greenhouse. However, the results in experiment 2 were likely more influenced by environmental conditions.

Similar experiments need to be repeated and new ones implemented in order to make definite conclusions. Even though allelopathy has been investigated for centuries, application to ornamental horticulture is very new, especially with mulch materials. These results should encourage interest for future research. It would be important if commercial mulches were available that exhibited natural, chemical properties for inhibiting weed seed germination, thereby reducing weeds and herbicide use in urban landscape.

LITERATURE CITED

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Al-Naib, Falah Abdul-Ghani and Elroy Rice. 1971. Allelopathic effects of Platanus occidentalis. Bulletin of the Torrey Botanical Club. 98(2):75-82.

Einert, A.E., R. Guidry, and H. Huneycutt. 1975. Permanent mulches for landscape plantings of dwarf crape myrtles. American Nurseryman. 142(11):9,59,62-65.

DeBell, Dean S. 1971. Phytotoxic effects of cherrybark oak. Forest Science. 17(2):180-185.

Elmore, C.D. 1985. Assessment of the allelopathic effects of weeds on field crops in the humid midsouth. in The Chemistry of Allelopathy. American Chemical Society, Washington, D.C. pp.21-32.

Fales, S.L. and R.C. Wakefield. 1981. Effects of turfgrass on the establishment of woody plants. Agronomy Journal. 73:605-610.

Fisher, Richard F. 1980. Allelopathy: a potential cause of regeneration failure. Journal of Forestry. 78(6):346-348.

Hook, Donal D. and Jack Stubbs. 1967. Observation of understory growth retardation under three species of oaks. U.S. Forest Service Research Note SE-70.

Lodhi, M.A.K. 1975. Allelopathic effects of hackberry in a bottomland forest community. Journal of Chemical Ecology. 1(2):171-182.

Lodhi, M.A.K. 1976. Role of allelopathy as expressed by dominating trees in a lowland forest in controlling the productivity and pattern of herbaceous growth. American Journal of Botony. 63(1):1-8

Lodhi, M.A.K. and Keith T. Killingbeck. 1982. Effects of pine-produced chemicals on selected understory species in a Pinus ponderosa community. Journal of Chemical Ecology. 8(1):275-283.

Mandava, N. Bhushan. 1985. Chemistry and biology of allelopathic agents. in The Chemistry of Allelopathy. American Chemical Society, Washington, D.C. pp.33-54.

Miller, Darrell A. 1983. Allelopathic effects of alfalfa. Journal of Chemical Ecology. 9(8):1059-1072.

Nielsen, A.P. and R.C. Wakefield. 1978. Competitive effects of turfgrass on the growth of ornamental shrubs. Agronomy Journal. 70:39-42.

Oleksevich, V.M. 1970. On the allelopathic activity of trees and shrubs used for landscape gardening. Physiological - Biochemical Basis of Plant Interactions in Photocenoses. U.S.S.R. 12:186-190.

Peters, E.J. and A.H.B. Mohammed Zam. 1981. Allelopathic effects of tall fescue genotypes. Agronomy Journal. 73(1):56-58.

Putnam, Alan R., Joseph DeFrank, and Jane P. Barnes. 1983. Exploitation of allelopathy for weed control in annual and perennial cropping systems. Journal of Chemical Ecology. 9(8):1001-1010.

Putnam, A.R. 1985. Allelopathy: An important mechanism of plant interference. Proceedings of the Western Society of Weed Science. 38:6-13.

Rice, Elroy L. 1974. Allelopathy. Academic Press, Inc. New York, New York. pp.353.

Rice, Elroy L. 1983. Pest Control with Nature's Chemicals. University of Oklahoma Press, Norman. pp.224.

Rietveld, W.J. 1975. Phytotoxic grass residues reduce germination and initial root growth of ponderosa pine. U.S. Forest Service Research Paper RM-153. pp.1-15.

Rietveld, W.J. 1983. Allelopathic effects of juglone on germination and growth of several herbaceous and woody species. Journal of Chemical Ecology. 9(2):295-308.

Shilling, Donn G., Rex A. Liebl, and A. Douglas Worsham. 1985. Rye(Secale cereale L.) and wheat(Triticum aestivum L.) mulch: The suppression of certain broadleaved weeds and the isolation and identification of phytotoxins. in The Chemistry of Allelopathy. American Chemical Society, Washington, D.C. pp.243-271.

Ward, H.A. and L.H. McCormick. 1982. Eastern hemlock allelopathy. Forest Science. 28(4):681-686.

Whitcomb, Carl E. 1972. Influence of tree root competition on growth response of four cool season turfgrasses. Agronomy Journal. 64:355-359.

Whitcomb, Carl E. 1981. Response of woody landscape plants to bermudagrass competition and fertility. Journal of Arboriculture. 7(7):191-194.

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