RELATIONSHIPS BETWEEN LANDSCAPE TREES AND GROUND COVERS

By

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CHAPTER I

INTRODUCTION

The popularity of ground covers has increased proportionally to the interest in upgrading the esthetic quality of the environment. This probably relates to the seasonal color and textural changes added to the landscape, as well as the ability to grow in full sun or shade if care is taken in choosing the right ground cover for a particular situation.

Turf grass frequently performs poorly beneath the canopies of large established trees (18, 43). Ground covers such as English ivy, Hedra helix (L.) or ajuga, Ajuga reptans (L.) have been used to cover these barespots with varying degrees of success. When the ground cover performs poorly, the responsible party generally does one or both of the following: (1) accepts the blame for not properly planting and/or maintaining the ground cover, or (2) blames the supplier for selling him poor quality plants.

Experts have many differing views regarding the poor performance of turf and/or ground covers in conjection with some trees. Some suggest the barespots beneath trees are the result of a reduction in light intensity, thereby reducing photosynthetic activity (18, 27). Others suggest the effects are due to competition from the tree. Since trees also have the majority of their effective feeder roots in the upper 6 to 12 inches of the soil, the ground cover or turf is in direct competition for water and nutrients (18, 45).

Recently researchers have theorized that allelopathic exudates by certain trees, either from leachets from the leaves, root exudations or from pollen being released and settling on the ground may influence the response of adjacent plants. Leachets have been shown to have an inhibitory effect on the growth and survival of certain neighboring plants (2). Most studies have been satisfied with simply identifying specific trees, shrubs and ground covers which exhibit this inhibitory effect.

It has long been recognized that specific ground covers grow and establish as understory plantings to certain trees where others cannot. However, there have been few studies conducted to determine if there are any beneficial or symbiotic relationships that could be exploited between specific trees and ground covers. It seems plausible that some ground covers might actually aid in the establishment and growth of a tree if the two were planted at the same time.

Ground covers are generally classified as being either sun or shade tolerant plants. However, these are not the only factors which affect establishment and growth. Factors such as drought tolerance, cold hardiness, ability to withstand foot traffic and perhaps ability to tolerate root competition from trees plays a major role in their survival and landscape performance.

There is a complex of interactions that occur between two or more plants living together in close association, defined as symbiotic relationships. Examples are: (1) commensalism, a relationship in which one species benefits from the presence of the other, while the second receives neither benefit nor harm; (2) parasitism, where one species benefits while the other is harmed; and (3) mutualism, where both species living together are somehow benefited by the presence of the other (19).

Most studies to date have been concerned with identifying and studying the parasitic relationship in order that it might be avoided. An example would be some of the studies conducted by Reavis and Whitcomb (33, 35) that show by controlling or eliminating weeds in a field or container nursery, you promote growth of the trees. However, Keeton (19) states that mutualistic relationships are probably the most dominating type of relationship that exists in nature, and from general and recorded observations, it is known that certain types of range grasses (6) and forest trees (42) are often found growing associated together in nature. If indeed these mutualistic relationships do exist in nature, it seems probable that certain types of ornamental ground covers would be better adapted to growing under specific species of landscape trees. It should be remembered that we are dealing with a landscape setting, much different from a native habitat in that competition for water and nutrients is often eliminated because both are applied as stress signs become visible.

In a preliminary study (38), significant differences were found between three ground covers growing in competition with two types of bare-root nursery trees. This study was designed to test an even wider variety of trees and ground covers while reducing some of the variations experienced using bare-root nursery trees in the earlier study.

The trees in this study were selected for their varying types of root systems (i.e., fibrous vs. coarsely structured), their shade density and their landscape popularity. Ground covers were chosen on their abilities to withstand shade, classification (both monocots and dicots), type of root systems and landscape popularity.

By first establishing the ground covers in two gallon black plastic bags, 6.5 liter (400 cu. in.) capacity, then transplanting a single, air root pruned tree seedling into the same two gallon bag, we attempted to measure the effects of an established ground cover on the growth and development of newly planted trees. Likewise, effects of trees on ground covers were obtained by comparing the growth response of a ground cover without competition and a ground cover grown with a particular tree.

CHAPTER II

LITERATURE REVIEW

Plants in Native Habitats

Trees in native habitats under intense competition display marked differences from those growing alone in open fields. Daubenmire (9) draws comparisons of growth habits by pointing out trees in the open tend to be exceptionally thick at the base with the trunk having a marked taper and branching throughout its height. When crowding starts to reduce the side lighting of a tree, the cambium is put into competition with the apical meristem for metabolites, so that height is stimulated at the expense of diameter growth. Therefore a tree in competition is likely to have a slender diameter, less side branching and greater height than a tree standing alone.

However, when two or more plants are grown within the same environment, interspecific competition for both above and below ground growth factors plays a major role in plant growth and development (11, 19). Separating the influences of each of the factors (ie., light, nutrition or moisture) is difficult but necessary in determining the influence of one plant on another.

Shoup and Whitcomb (38) and Karnok (18) found that relationships between trees and ground covers seems to be species specific. Even slight differences in varieties or cultivars may yield vastly different results (18, 20).

Field Studies of Plant Relationships

Most tree-groundcover relationship studies have dealt with plants in native habitats. Studies of this nature alone are difficult because of problems with fluctuations in light intensities, soil consistency, soil moisture and aeration, environmental conditions from year to year, types and densities of plant populations and difficulties encountered in evaluating root systems of plants in field soils (8, 10, 11, 28, 40, 42). However for all of their difficulties, field studies have provided a vast amount of information pertinent to plant relationships.

Commonly, two techniques are employed in field research. One involves a method of detailed observation and manipulation of the aerial environment (9), while the second employs trenching to alter the below ground environment (9, 10, 27, 28).

The observation system studies the aerial environment of a plant community without removing or destroying any plants present. By manipulating existing conditions (i.e., increasing light intensities with pruning, removing organic litter, increasing water or nutrients) changes in plant responses can be measured and recorded.

Trenching keeps the aerial environment intact and employs digging a ditch around the treatment plot to sever any roots which may be inhibiting the growth of understory plants, either through competition or allelopathic root exudates.

Container Studies of Plant Relationships

Containers offer the unique opportunity to study both the aerial and root components of plants at one time. However, the container system is totally different than a field situation. Whitcomb (34, 46, 47, 49) has reported on factors such as drainage, porosity, media components, nutrition and temperature, which are unique to the container system. These reports help one understand the complexity of the system and unless well understood, data from container studies can lead to distorted or unreliable conclusions.

Welbank's thumb-pot technique (11, 41) and Whitcomb's connecting pot system (48), are two unique container modifications that allow two plants to be placed directly into competition with each other while keeping environmental factors such as light, water, oxygen, nutrients, and space constant. An added advantage to these systems is that any or all of the constants (oxygen, water, etc.) can be varied. The main disadvantage is the results serve only as a guide or theory until field testing can prove or disprove the results.

Competition

Keeton (19) defines competition as a struggle for existence among living organisms within the same environment. This struggle for existence involves competition among plants for water, nutrients, light, carbon dioxide, oxygen and space (9). In field studies, separating which growth factor(s) is responsible for the reduction in plant growth becomes very difficult. Also, plants have differences in their inherent, genetic capabilities to compete. These differences are subject to change with the environmental fluctuations that can occur over relatively short distances (9, 29).

Many cases of competition have been recorded. Clark and McLearn (8) reported survival, growth and mass of *Pinus corotra* seedlings were reduced as the grass, *Dactylis glomerata*, density increased. They also reported that grass by itself was reduced by intraspecific competition. Stewart and Beebe (39) report that survival of ponderosa pine seedlings increased as native range grasses were controlled. Burdom and Pryor (7) state that eucalyptus seedlings when grown two or more to a pot singificantly reduced overall plant performance as opposed to seedlings grown singly. Many other studies report similar findings when studying tree vs. tree, or tree vs. understory vegetation (13, 21, 22, 26, 27, 30, 33, 35, 43, 44).

Competition for nitrogen has been suggested as a key factor in the reduction of plant growth. Bould and Jarrett

(5) reported cover crops of Lolium perenne and Poa pratensis reduced growth, yield and foliar nitrogen in apple trees. Similarly, Van der Boon (4) reported increased yields and foliar nitrogen concentrations in apple trees where competition was reduced by clean cultivation. Richardson (36) showed that Lolium perenne root competition for nitrogen depressed root growth, shoot growth and leaf development on Acer pseudoplatanus.

Harris (16) reported a decrease in girth and growth of Magnolia grandiflora and Zelkova serrata resulted from an established Festuca arundinacea turf in a landscape environment. He also reported that nitrogen fertilization was effective in reducing the effects of the turf. Contrarily, Whitcomb (45) showed little benefit from fertilizer applications to reduce the effects of a well established U-3 bermuda grass on the growth and development of dwarf burford holly, golden vicary privet, pfitzer juniper or japanese black pine. The best treatment showed that keeping a 30 inch (194 sq. cm) square around the woody plant free of grass competition from around the base would reduce the shock of competition and aid in the establishment and growth of a newly planted tree or shrub. Many other reports exist concerning the reduction in growth of a tree from the presence of other trees or understory growth (7, 8, 30, 38, 39, 43, 44).

Allelopathic Responses

There are some types of plant interactions which involve the release of chemical substances from one plant which have an influence upon another plant. Most noticeably this influence is inhibitory, and this type of substance is known as an allelopathic exudate (5, 11, 29, 42).

Sources of the exudates can be by throughfall (19), (which is essentially rainwater leaching chemicals from the foliage of trees as it passes through the canopy), guttation, root leachates, decomposing organic litter (leaves, bark, stems), or gasses released from plants (especially terpenoids released from pines, junipers and eucalyptus trees) (50). Whittaker (50) presented a sizeable listing of reference works on allelopathic exudates, chemical composition and plant sources.

Research by Gant and Clebsch (15) observed that ten herbaceous species existed exclusively outside of sassafras clumps while seven other herbaceous species were found directly beneath the clumps. They concluded that the herbaceous species are either (a) slowly evolving tolerances to the toxic chemicals released by sassafras, or (b) the chemicals are acting as a stimulus to some plant species, or (c) the chemicals released are somewhat species specific in their toxicities. Terpenes were identified as the inhibiting chemical compound.

Another study by Wiant and Ramirez (51) found that white pine, Pinus strobus was stunted by black walnut and suggested planting no closer than the expected height of the walnut tree. A USDA Forest Service report (2) showed that root leachates from sugar maple, Acer saccharum, when applied to germinated seedlings of spruce, pines, arborvitae and birch, that only arborvitae seedlings were not as a direct result, stunted. Retveld (37) found that extracts from dead organic matter of Festuca arizonica significantly reduced germination, radical elongation and height of Pinus ponderosa seedlings. Lodhi (24) observed poor growth of herbaceous plants beneath the canopies of Platanus spp., Celtis spp., Quercus borealis and Quercus alba and identified phenolic compounds from soil and decayed leaf leachates as the inhibitor. Horsley (17), Fisher et al. (12) and Weeds (3), all found golden rod and aster to be delterious to black cherry, sugar maple, and black locust respectively. Many other allelopathic effects are found in the literature (1, 2, 6, 14, 21, 22, 23, 24, 25, 30, 31, 32, 34, 37).

Whittaker (5) in conclusion, states that allelopathy is a secondary chemistry of defense which is universal among higher plants. The examples of allelopathic effects recorded to date are probably only of the most conspicuous cases. Allelopathy by itself is not a pecularity of a few plants, but a widespread and normal, although mostly inconspicuous, phenomenon of natural communities.

Mutualism

There are types of relationships that exist between plants of different species, where recorded growth factors have shown a positive benefit when growing in the same environment. Went (42) describes finding the orchid, *Oberonia oxystophyllum* in a forest on the island of Java, that grew only on a particular host tree *Saurauia penduliflora*. He describes environments where branches of the host tree grew intermixed with the branches of *Cestrum aurantiacum*, yet the orchid remained exclusively on the host. Desert plants in a totally different environment have shown similar specificity between certain shrubs and particular herbaceous plants (42).

Several papers have been published that indicate at least a compatible relationship between two plants in a restricted environment. Peer (30) reported a container experiment using two year old seedlings of spruce, *Picea pungens*, with six weed species. He tested the effects of competition on height, stem diameter, top and root weight, visual grade, mycorrhizal infection of roots, color and nutrient content of needles and found that *Rubus idaeus*, *Rubus frutciosus* and *Cirsium arvense* had little or no effect on the spruce seedlings. On the other hand, toxins produced by goldenrod, broomsedge, Queen Anne's lace, crownvetch and Timothy reduced height of black locust seedlings by 50%, but, European alder, *Alnus glutinosa* was not affected by any of the weeds tested (3). Similar findings can be found in other research papers (15, 20, 21, 22, 23, 41, 43, 44).

Most studies on mutual relationships to date have been between forest trees and understory plants. Only one reference was found that dealt with ornamental ground covers and landscape trees in a man-managed environment. Shoup and Whitcomb (38) evaluated three ornamental ground covers growing with two landscape trees in a container study. All environmental elements such as light, water, nutrients, oxygen and space were held constant for one full growing season. Striking differences were reported in the severity of the competition of the ground covers incurred on the trees (Table I).

Went (42) stated that the mutualism or specificity that certain plants exhibit towards one another must have a chemical attraction or basis for their relationship. If chemicals can be secreted by plants that are allelopathic or inhibitory, why can't stimulators be extracted as well?

The purpose of this study was to determine the relationships between 10 ground cover plants common in the man-managed landscape and 6 landscape trees. Landscape performance may be improved and maintenance decreased if trees and ground covers can be identified that are symbiotic or mutualistic as opposed to directly competitive or inhibitory where an allelopathic condition may exist.

TABLE I

EFFECTS OF COTTONWOOD AND SILVER MAPLE ROOTS ON GROWTH OF GROUND COVERS

		Cottonwood	Control Without Tree Roots	% Change
English Ivy	Tops g*	46	83	44%
	Roots g	5	13	60%
Liriope	Tops	37	61	38%
	Roots	23	33	32%
Dwarf Bamboo	Tops	6	8	+25% NS
	Roots	14	17	20% NS

		Silver Maple	Control Without Tree Roots	% Change
English Ivy	Tops g	68	86	21% NS
	Roots g	9	11	18% NS
Liriope	Tops	63	68	7% NS
	Roots	42	50	16% NS
	Tubers	14	5	28%
Dwarf Bamboo	Tops	4	4	No Change
	Roots	16	29	43%
	Rhizomes	18	35	50%

* g stands for top or root weights in grams.

CHAPTER III

METHODS AND MATERIALS

Ten ground covers and six tree species were selected for this study. The species selected represent a wide range of adaptable landscape plants (Table II).

The connecting pot technique developed by Whitcomb (43) and used in the 1978 study (38) was modified to allow use of tree seedlings grown in bottomless milk cartons to eliminate variation experienced with field dug bareroot trees. The milk carton seedlings were started February 1, 1980 on expanded metal benches in a solar heated greenhouse to allow them to reach a transplantable size by early June. The milk cartons measured 2 3/4" square by 5" deep for a total volume of 37.8 cu. in. Two or more seeds were planted directly into the milk carton and thinned at germination to one healthy seedling per carton.

Ground covers (with the exception of bermuda grass and fescue) were propagated asexually from cuttings or divisions between December 20, 1979 and January 15, 1980. All were grown in 2"x2"x2" individual propagation pots either in a mist house (cuttings) or in a gas heated greenhouse (divisions).

TABLE II

TYPES OF GROUND COVERS TO BE USED

1.	Cynodon dactylon	Common Bermudagrass
2.	Euonymus fortunei 'Coloratus'	Evergreen Eunoymus
3.	Festuca rubra	Red Fescue
4.	Hedera helix	English Ivy
5.	Liriope muscari	Liriope
6.	Ophiopogen japonicus	Mondo Grass
7.	Pachysandra terminalis	Japanese Spurge
8.	Sasa pigmaea	Dwarf Bamboo
9.	Vinca major	Periwinkle
10.	Vinca minor	Common Periwinkle

TYPES OF TREES TO BE USED

1.	Acer saccharum 'Caddo'	Caddo Sugar Maple
2.	Cercis chinesis	Chinese Redbud
3.	Pinus thunbergi	Japanese Black Pine
4.	Populus deltoides	Cottonwood
5.	Taxodium distichum	Bald Cypress
6.	Ulmus parvifolia	Lacebark Elm

Propagation medium consisted of a 1:1 ratio of peat to perlite. Nutrients added at time of mixing were 6 lbs. per cu. yd. of 18-6-12 osmocote and 1 lb. per cu. yd. of Micromax micronutrients. Once cuttings rooted they were moved from the mist greenhouse to prevent unnecessary leaching of nutrients from the foliage by the mist.

A well established U-3 bermuda grass turf plot served as a source for 1½" diameter plugs. Three plugs, 2" deep were planted into the two gallon bag and allowed to establish for one month. The Kentucky-31 Fescue was seeded directly into the bags at a rate of 4 lbs. (1816 gms.) of seed per 1,000 sq. ft.

Growing medium for tree seedlings consisted of a 1:1 ratio of peat to perlite. Nutrients added at time of mixing were 9 lbs. (4086 gms.) per cu. yd. of 18-6-12 osmocote and 1 lb. (454 gms.) per cu. yd. of Micromax micronutrients.

On May 5, the cuttings were brought out of the greenhouses and planted into two gallon black plastic bags. The growing medium in the bags consisted of a 3:1:1 ratio of bark (1¼" screenings), peat and sand, respectively. The mix had a 24% porosity level to supply adequate oxygen to the plants root system.

All nutrients essential for good plant growth for a full growing season were incorporated with the components as they were mixed in a 2.5 cu. yd. capacity cement mixer. Nutrients added were: 14 lbs. (6356 gms.) per cu. yd. of 18-5-11 osmocote, 8 lbs. (3632 gms.) per cu. yd. of dolomitic limestone, 4 lbs. (1816 gms.) per cu. yd. of gypsum, 2 lbs. (908 gms.) per cu. yd. of triple superphosphate (0-46-0) and 1.5 lbs. (681 gms.) per cu. yd. of Micromax micronutrients.

The ground covers were allowed to grow and establish for approximately one month before the tree seedlings were planted directly into the same two gallon bags. In order to avoid any destruction to the root system of the ground covers, an aluminum can (approximately same shape and volume as a milk carton) was placed directly in the center of the two gallon bag when the ground covers were planted. Therefore, on June 20, when the tree seedlings were transplanted from the cartons to the bags, the can was removed and the tree seedling was slipped into the unoccupied space.

The experiment was set up as a completely randomized design. Six different tree species were used in combinations with ten different ground covers along with two controls: (a) trees without competition, and (b) ground covers without competition, for a total of 62 treatments with 6 replications of each treatment and a total of 372 pots.

Environmental factors such as light, water, nutrients and available growing space were held constant among all plants. The study was conducted under a 22% shade structure measuring 30' x 70'. Pots were spaced on 1.5 foot centers to reduce plant to plant shading as much as practical. Light meter readings varied greatly depending upon time of day, sun angle, sky conditions and placement or location of

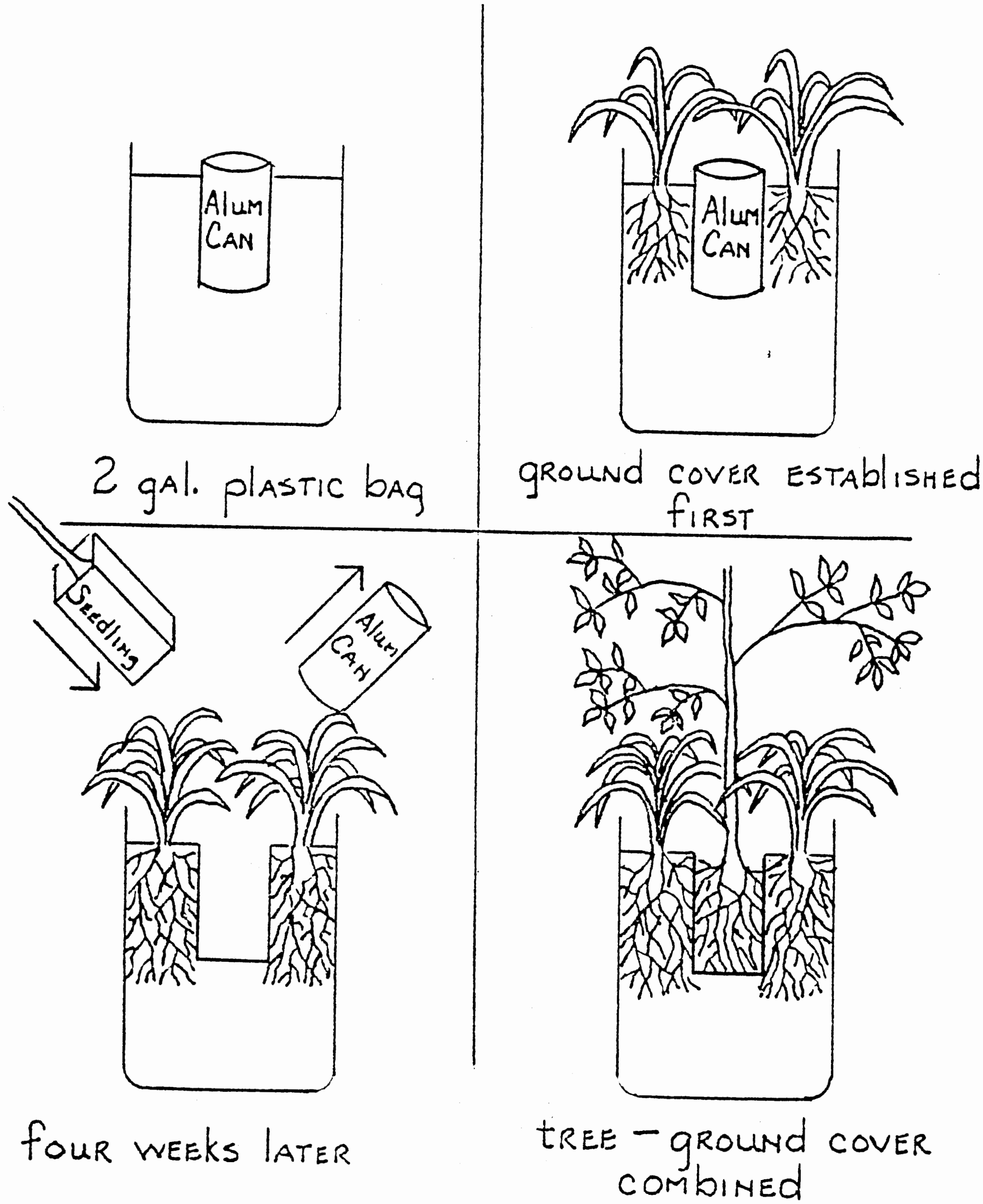

Figure 1. Schematic Showing Planting Procedure

light meter, but averaged approximately 40% less light to the ground cover (underneath the canopy) than light measured in full sun.

Water was applied through an overhead sprinkler system as needed. No herbicides were used in the study. All weeds were pulled by hand to prevent any herbicidal influence on the growth of ground covers.

Evaluation Techniques

All trees except cottonwoods, Populus deltoides (which were propagated from hardwood cuttings) were grown from seed. Thus, the possibility of substantial genetic variability among the seedlings existed (9). Seedlings used were selected for uniformity in size and appearance at the time of planting, however, additional genetic differences were noted. Since ground covers were mostly asexually propagated from one parent plant, little, if any, genetic variability existed.

The initial height and caliper of all tree seedlings was recorded on June 20. On October 26, the final height and caliper was recorded and the increase in growth was determined.

A visual grade was taken on all ground covers. This was accomplished by selecting standards, rated 1, 4, 7 and 10 (1=poor; 10=best), from plants in the study. Five people evaluated all ground cover-tree combinations. The mean of the five visual evaluations was used in the statistical analysis. After the visual evaluations were complete, fresh top weights were recorded for all trees and ground covers.

Once the top portion of the plant had been visually graded and weighed, an attempt was made to remove the growing medium and separate tree roots from ground cover roots. Notes were taken on the general appearance of the roots in the containers, i.e., (a) were roots intermingled or naturally separated; (b) were the roots of the trees or ground covers restricted to the upper 4" of the pot or did they extend to the bottom; and (c) were the new roots formed typical of the species.

Once the general appearances and observations were recorded, a visual grade on a scale of 1 to 10 was taken for the roots of both trees and ground covers. The scaling criteria for tree and ground cover roots was as follows:

Visual Scale for Tree Roots

1	Tree roots confined to original planting hole.
4	Tree roots slightly intermingling with ground covers.
7	Moderate intermingling of tree and ground cover roots.
10	Proliferation of tree roots throughout container.

Visual Scale for Ground Cover Roots

1	No roots below 2" deep.
4	No roots below 4" deep.
7	Roots to bottom, but only at perimeter of bag (little intermingling).
10	Roots to bottom of bag, much root intermingling.

Following visual root ranking, fresh root weights were recorded for all trees and ground covers except the treatments with bermudagrass and Fescue. The bermudagrass grew so vigorously among the tree roots that the two could not be separated accurately. The fescue had a very fibrous root system and with most treatments was completely engulfed by the tree's root system, making separation impossible.

CHAPTER IV

RESULTS AND DISCUSSION

Effects of Ground Covers on Trees

Bald Cypress

Root and top weight, visual grade of tree roots, and stem caliper of bald cypress combined with English ivy was equal to bald cypress growing alone (Table III). Root weight and top weight of bald cypress combined with pachysandra and mondo grass were equal to bald cypress alone.

Vinca minor and Kentucky-31 fesuce had mixed effects on bald cypress. *V. minor* reduced the visual grade and restricted root weight of bald cypress compared to bald cypress grown alone. At the same time bald cypress combined with *V. minor* equaled bald cypress grown alone in terms of stem caliper and top weight. Kentucky-31 fescue restricted top weight and stem caliper of bald cypress but had no detrimental effect on the visual grade of bald cypress tree roots.

Bermudagrass, dwarf bamboo, euonymus and liriope were the most restrictive ground covers on the growth of bald cypress (i.e., root weight, stem caliper, top weight and visual grade of tree roots). *Vinca major* reduced root

TABLE III

EFFECTS OF GROUND COVERS ON BALD CYPRESS

Cypress	Control	Bermu	Fescue	Bamboo	V. Minor	V. Major	Ivy	Euon.	Liriope	Pachy	Mondo
Top Weight	205[w] d[x]	93 a	145 b	166 bc	190 cd	163 bc	214 d	138 b	157 bc	213 d	188 cd
Root Weight	138 d	NA[y]	NA	99 ab	103 abc	107 abc	133 cd	81 a	109 abc	150 d	120 bcd
Height	NS[z]	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Stem Caliper	1.4 c	.78 a	1.05 b	1.13 b	1.21 bc	1.18 b	1.21 bc	1.05 b	1.01 b	1.18 b	1.21 bc
Visual Grade Roots	9.5 d	5.2 a	9.3 cd	5.8 ab	6.5 ab	7.3 b	7.8 cd	6.7 ab	6.5 ab	7.5 bc	7.0 ab

[w] Numbers are means of 6 replications for each treatment
[x] Values in rows followed by the same letter are not significantly different at the 5% level
[y] NA - data not available
[z] NS - No significant differences among treatments

weight, top weight and visual grade of bald cypress roots but had only a moderate effect on the stem caliper of tree roots when compared to bald cypress grown alone.

No ground cover - bald cypress combination had any effect on height of bald cypress when compared to bald cypress alone. Kentucky-31 fescue and bermudagrass roots were so intermingled with bald cypress that separation was not possible.

Lacebark Elm

Top weight and height of lacebark elm, combined with English ivy and pachysandra were equal to elms grown alone (Table IV).

Lacebark elm with dwarf bamboo produced root and top weights equal to elm alone. However, elms did not grow as tall and visual grade of tree roots were lower when dwarf bamboo was present. Liriope restricted both tree root weight and top weight and root visual grade. Mondo grass had no detrimental effect on top weight and height of trees but restricted both root weight and visual grades of tree roots compared to elms growing alone. Kenutcky-31 fescue restricted top weight and height of trees but increased the visual grade of elm tree roots.

The most severe competitor, *Vinca minor* restricted root weight, height of trees and visual grade of elm roots. Bermudagrass restricted both the top weight and height of elm trees.

TABLE IV

EFFECTS OF GROUND COVERS ON LACEBARK ELM

Elm	Control	Bermu	Fescue	Bamboo	V. Minor	V. Major	Ivy	Euon.	Liriope	Pachy	Mondo
Top Weight	151[w] cd[x]	92 a	111 ab	146 cd	138 bc	147 cd	171 d	145 cd	116 ab	160 cd	133 bc
Root Weight	205 c	NA[y]	NA	168 bc	135 ab	144 ab	150 ab	139 ab	116 a	166 b	126 a
Height	62.7 d	40.5 ab	39.3 a	40.8 ab	37.0 a	51.3 bc	63.0 d	60.5 cd	61.5 cd	54.8 cd	61.7 cd
Stem Caliper	NS[z]	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Visual Grade Roots	9.8 e	7.2 cd	9.0 e	4.2 a	5.8 b	6.3 bc	7.2 cd	7.7 d	7.5 d	7.5 d	6.3 bc

[w] Numbers are means of 6 replications for each treatment
[x] Values in rows followed by the same letter are not significantly different at the 5% level
[y] NA - data not available
[z] NS - No significant differences among treatments

Stem caliper of elm trees were not significantly different among any of the tree-ground cover combinations.

Japanese Black Pine

Japanese black pine (Table V) combined with Vinca major grew equal to Japanese black pine alone in terms of top weight, increased stem caliper and increased height. Pachysandra had no effect on top weight and visual grade of tree roots and only moderately restricted stem caliper and tree height.

Japanese black pine in combination with euonymus equaled pines grown alone in root weight and height of trees, but stem caliper, top weight and visual grades of tree roots were severely restricted. Similarly, pines with mondo grass were about the same as pine alone in stem caliper and top weight, but visual grade of tree roots, tree root weights and height was severely restricted. Japanese black pine with English ivy equaled pine alone in stem caliper and height but had lower top and root weights and visual grade ratings for tree roots.

Bermudagrass restricted all parameters measured (i.e., stem caliper, top weight, visual grade of tree roots and height of trees) of Japanese black pine. Growth of Japanese black pine was also restricted by liriope (stem caliper, top weight, height and visual grade of pine tree roots) except for root weight which was about the same as pine alone.

TABLE V

EFFECTS OF GROUND COVERS ON JAPANESE BLACK PINE

Pine	Control	Bermu	Fescue	Bamboo	V. Minor	V. Major	Ivy	Euon.	Liriope	Pachy	Mondo
Top Weight	39.6[w] d[x]	23.6 a	25 ab	32 bcd	24.6 a	33.5 cd	30.3 abc	23.8 a	24 a	34.8 cd	33.1 cd
Root Weight	15.2 e	NA[y]	NA	4.3 ab	3.5 a	10.7 cd	8.7 c	14.5 de	11.2 cde	9.8 c	7.7 abc
Height	8.5 d	4.5 a	7.7 bcd	6.2 ab	7.5 bc	9.7 d	9.7 d	7.7 bcd	5.2 a	6.5 abc	6.2 ab
Stem Caliper	.312 c	.216 ab	.216 ab	.25 bc	.25 bc	.267 bc	.267 bc	.167 a	.216 ab	.233 ab	.267 bc
Visual Grade Roots	7.8 e	5.17 d	3.0 ab	3.8 bc	2.3 a	5.0 cd	4.3 bcd	4.8 cd	3.17 ab	6.67 e	5.17 d

[w]Numbers are means of 6 replications for each treatment
[x]Values in rows followed by the same letter are not significantly different at the 5% level
[y]NA - data not available

Kentucky-31 fescue with pine restricted stem caliper, top weight and visual grade of tree roots and Vinca minor reduced root weights, top weights and visual grades of roots of Japanese black pine.

Cottonwood

Pachysandra combined with cottonwood, produced the best results of any ground cover-cottonwood combination (Table VI). Height of cottonwood was significantly greater when combined with pachysandra compared to cottonwood trees grown alone. Cottonwood root weights and tree root visual grades with pachysandra were equal to trees alone. Only stem caliper of cottonwoods was slightly reduced by pachysandra.

Where English ivy or euonymus were present with cottonwood, both stem caliper and height of trees were equal to cottonwoods alone, however, both ground covers supressed root weights of cottonwoods.

Liriope combined with cottonwood reduced root weight, stem caliper and root visual grade. Bermudagrass restricted stem caliper, visual grade of tree roots and height. Vinca minor supressed both root weight and stem calipers.

No differences were significant for top weights of trees among any cottonwood-ground cover treatments.

Caddo Maple

Few ground covers showed any consistent relationships

TABLE VI

EFFECTS OF GROUND COVERS ON COTTONWOOD

CW	Control	Bermu	Fescue	Bamboo	V. Minor	V. Major	Ivy	Euon.	Liriope	Pachy	Mondo
Top Weight	NS[w]	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Root Weight	302.3[x] e[y]	NA[z]	NA	262.8 de	183.8 ab	211.3 abc	180.8 ab	181.8 ab	170.8 a	254 cde	223.6 bcd
Height	66.0 ab	57.3 a	65.7 ab	76.0 cde	67.2 ab	77.5 cde	85.7 e	85.0 e	71.3 bcd	79.0 de	69.0 bc
Stem Caliper	.75 c	.45 a	.6 b	.6 b	.516 ab	.583 ab	.65 bc	.633 bc	.516 ab	.6 b	.55 ab
Visual Grade Roots	10.0 e	6.0 a	9.17 de	7.83 b	9.17 de	9.0 bcde	7.8 b	8.3 bc	8.17 bc	10.0 e	9.5 e

[w] NS - No significant differences among treatments
[x] Numbers are means of 6 replications for each treatment
[y] Values in rows followed by the same letter are not significantly different at the 5% level
[z] NA - data not available

with caddo maple (Table VII). Pachysandra with maple produced root weights and root visual grades of maple also equal to the control.

Euonymus combined with maple restricted root weight of the tree but the stem caliper was unaffected.

Liriope, bermudagrass and dwarf bamboo were the most severe competitors with maple by restricting all parameters measured (i.e., root weight, stem caliper and visual grade of tree roots) when compared against maple controls.

Both top weight and height of caddo maple were not significantly affected by any of the maple-ground cover treatments.

Chinese Redbud

Kentucky-31 fescue proved to be the most compatible ground cover with Chinese redbud (Table VIII) by producing no negative effects on stem calipers, height and tree root visual grades. Chinese redbud with dwarf bamboo likewise had stem caliper and tree height equal to Chinese redbud growing alone, however, root weight and visual grade of tree roots were restricted. Mondo grass increased the visual grade of Chinese redbud roots but restricted the height of trees.

Liriope grown in combination with Chinese redbud restricted root weight, stem caliper, visual grade of tree roots and height of trees. Pachysandra and mondo grass supressed both stem caliper and height of trees when combined with Chinese redbud.

TABLE VII

EFFECTS OF GROUND COVERS ON CADDO MAPLE

Maple	Control	Bermu	Fescue	Bamboo	V. Minor	V. Major	Ivy	Euon.	Liriope	Pachy	Mondo
Top Weight	NS[w]	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Root Weight	22.0[x] cd[y]	NA[z]	NA	13.3 ab	16.8 bc	17.8 bcd	15.3 abc	11.7 ab	9.2 a	23.8 d	21.2 cd
Height	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Stem Caliper	.216 c	.03 a	.133 bc	.116 b	.116 b	.05 ab	.133 bc	.133 bc	.05 ab	.116 b	.116 b
Visual Grade Roots	9.17 e	3.83 ab	5.3 bc	2.67 a	4.33 b	4.0 ab	4.8 b	6.67 cd	2.5 a	7.83 de	6.83 cd

[w]NS - No significant differences among treatments
[x]Numbers are means of 6 replications for each treatment
[y]Values in rows followed by the same letter are not significantly different at the 5% level
[z]NA - data not available

TABLE VIII

EFFECTS OF GROUND COVERS ON CHINESE REDBUD

Redbud	Control	Bermu	Fescue	Bamboo	V. Minor	V. Major	Ivy	Euon.	Liriope	Pachy	Mondo
Top Weight	NS[w]	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Root Weight	66.8[x] d[y]	NA[z]	NA	30.8 ab	45.0 bc	47.6 c	39.7 bc	42 bc	19.5 a	47.8 c	45 bc
Height	54.0 cde	56.2 e	48.5 cde	61.5 e	43.0 bcd	42.7 bcd	46.3 cd	42.2 cd	27.3 a	30.7 ab	41.7 bc
Stem Caliper	.5 c	.47 bc	.53 c	.53 c	.5 c	.42 abc	.45 bc	.37 ab	.32 a	.35 a	.43 abc
Visual Grade Roots	8.8 f	4.17 ab	8.5 f	4.67 bc	5.68 cd	7.5 ef	7.0 de	4.3 ab	3.0 a	8.3 ef	8.67 f

[w] NS - No significant differences among treatments
[x] Numbers are means of 6 replications for each treatment
[y] Values in rows followed by the same letter are not significantly different at the 5% level
[z] NA - data not available

No significant differences were found among Chinese redbud-ground cover combinations.

A summation of the Effects of Ground Covers on Trees is presented in Table IX. It is interesting to note that English ivy and pachysandra were compatible with all trees except Chinese redbud. Euonymus was found to be compatible with lacebark elm, Japanese black pine and cottonwood.

The most non-compatible ground covers were bermudagrass and liriope which severely restricted growth of bald cypress, lacebark elm, pine, cottonwood and caddo maple.

Effects of Trees on Ground Covers

Bermudagrass

Although bermudagrass suppressed all growth parameters of trees, trees likewise suppressed growth of bermudagrass. There were two exceptions, however: bermudagrass combined with cypress and pine had visual grades of bermudagrass roots equal to bermudagrass grown alone (Table X). Pines had less of an effect on bermudagrass (although statistically significant) than other trees. Cypress and redbud likewise had only a moderately restrictive effect on the growth and development of bermudagrass.

Cottonwood and elm combined with bermudagrass severely restricted top and root weight and top and root visual grade of bermudagrass. Surprisingly, maple, the slowest growing tree species used, severely restricted the growth of bermudagrass in all parameters measured.

TABLE IX

SUMMARY OF THE EFFECTS OF GROUND COVERS ON TREES

Bald Cypress

Compatible	Non-compatible
1. English Ivy	1. Bermudagrass
2. Pachysandra	2. Dwarf bamboo
3. Mondo Grass	3. Euonymus
4. Vinca minor	4. Liriope

Lacebark Elm

Compatible	Non-compatible
1. English Ivy	1. Bermudagrass
2. Pachysandra	2. Liriope
3. Euonymus	3. Fescue
4. Dwarf bamboo	4. Vinca minor

Japanese Black Pine

Compatible	Non-compatible
1. Vinca major	1. Bermudagrass
2. English Ivy	2. Liriope
3. Pachysandra	3. Vinca minor
4. Euonymus	4. Fescue

Cottonwood

Compatible	Non-compatible
1. Pachysandra	1. Bermudagrass
2. English Ivy	2. Liriope
3. Euonymus	
4. Mondo Grass	

Caddo Maple

Compatible	Non-compatible
1. Pachysandra	1. Liriope
2. English Ivy	2. Bermudagrass

TABLE IX (Continued)

Compatible	Non-compatible
Caddo Maple (Continued)	
	3. Dwarf bamboo
	4. Vinca major
Chinese Redbud	
1. Fescue	1. Liriope
2. Vinca major	2. Pachysandra
3. Mondo Grass	3. Euonymus
4. Dwarf bamboo	4. Vinca minor

Root weights for bermudagrass were not available for any of the tree species used.

Fescue

Effects of trees on fescue were measureable only in terms of visual grade of tops and roots of fescue. Top weights of fescue showed no significant differences among treatments and there was no data avilable for root weights. Variability among tree-fescue treatments makes conclusion statements difficult.

Fescue combined with pine, maple and redbud produced visual grades of fescue tops and roots equal to fescue grown alone (Table XI). Cottonwood and elm restricted the visual grade of tops and roots of fescue. Cypress was an intermediate by suppressing the visual grade of fescue roots and

TABLE X

EFFECTS OF TREES ON BERMUDAGRASS

Bermudagrass	Control	Cypress	Elm	Pine	CW	Maple	Redbud
Top Weight	47.6[w] d[x]	34.0 bc	27.4 ab	35.1 c	26.8 c	28.7 abc	33.0 abc
Root Weight	NA[y]	NA	NA	NA	NA	NA	NA
Visual Grade Tops	7.9 d	5.4 bc	4.2 a	6.4 c	4.0 a	4.6 ab	5.6 bc
Visual Grade Roots	9.1 d	8.1 cd	5.2 a	8.2 cd	6.2 ab	7.5 c	7.1 bc

[w] Numbers are means of 6 replications for each treatment
[x] Values in rows followed by the same letter are not significantly different at the 5% level
[y] NA - data not available
[z] NS - No significant differences among treatments

TABLE XI

EFFECTS OF TREES ON FESCUE

Fescue	Control	Cypress	Elm	Pine	CW	Maple	Redbud
Top Weight	NS[w]	NS	NS	NS	NS	NS	NS
Root Weight	NA[x]	NA	NA	NA	NA	NA	NA
Visual Grade Tops	8.4[y] cd[z]	4.6 bc	4.1 a	9.4 d	4.3 ab	7.0 bcd	6.0 abc
Visual Grade Roots	8.6 bc	4.6 a	5.5 a	9.5 c	4.6 a	7.1 abc	6.7 ab

[w] NS - No significant differences among treatments
[x] NA - data not available
[y] Numbers are means of 6 replications for each treatment
[z] Values in rows followed by the same letter are not significantly different at the 5% level

at the same time produced tops equal to fescue controls.

Dwarf Bamboo

Dwarf bamboo was restricted by most trees in all but one parameter. Top weights of bamboo combined with pine were equal to bamboo growing alone (Table XII). Pines also had the least total effect on bamboo root weight and visual grades of tops and roots but were significantly less than bamboo controls.

Redbud and maple followed pine in their compatible relationship with bamboo when compared to the effect of other tree species on bamboo. Cottonwood, elm and cypress had the most detrimental effect on bamboo growth and development.

Vinca minor

Vinca minor was restricted by most trees. Top weights of *V. minor* combined with pine were equal to *V. minor* growing alone (Table XIII). Pines also had the least total effect on *V. minor* root weight and visual grades of tops and roots.

Maple and redbud followed pine in their compatible relationship with *V. minor*. Cottonwood, elm and cypress, combined with *V. minor* had the most detrimental effects on growth and development of *V.* minor.

Vinca major

Pine combined with *V. major* produced top weights and

TABLE XII

EFFECTS OF TREES ON DWARF BAMBOO

Dwarf Bamboo	Control	Cypress	Elm	Pine	CW	Maple	Redbud
Top Weight	26.7[w] e[x]	17.1 ab	14.6 a	25.2 de	13.4 a	19.1 bc	21.6 cd
Root Weight	151.1 d	92.5 b	72.0 a	109.2 c	65.7 a	79.1 ab	91.1 b
Visual Grade Tops	8.4 d	5.7 bc	4.0 a	6.2 c	4.5 ab	5.5 abc	6.1 c
Visual Grade Roots	10.0 d	5.2 b	4.5 b	7.1 c	3.4 a	6.1 c	6.7 c

[w] Numbers are means of 6 replications for each treatment

[x] Values in rows followed by the same letter are not significantly different at the 5% level

TABLE XIII

EFFECTS OF TREES ON VINCA MINOR

Vinca Minor	Control	Cypress	Elm	Pine	CW	Maple	Redbud
Top Weight	153.0[w] e[x]	85.4 b	74.2 b	125.4 de	36.7 a	120.2 cd	98.5 bc
Root Weight	142.4 c	92.4 b	85.9 b	136.2 c	64.0 a	93.9 b	82.9 b
Visual Grade Tops	9.5 d	5.4 b	5.5 b	7.8 c	3.1 a	6.1 b	6.1 b
Visual Grade Roots	9.2 c	5.9 b	3.7 a	8.1 c	3.5 a	6.2 b	6.0 b

[w]Numbers are means of 6 replications for each treatment
[x]Values in rows followed by the same letter are not significantly different at the 5% level

visual grades of tops and roots equal to _V. major_ grown alone (Table XIV). However, root weights of _V. major_ when combined with pines were only slightly reduced.

Redbud and maple were similar to pine in their relationship with _V. major_ as both top weights and visual grades of tops, equaled _V. major_ grown alone. At the same time both redbud and maple restricted root weight and root visual grade of _V. major_. Visual grade of tops of _V. major_, with cypress, were equal to the controls. However, cypress supressed top and root weight and root visual grade of _V. major_.

Cottonwood and elm drastically restricted the overall growth performance of _V. major_.

English Ivy

All growth parameters for English ivy, when combined with pine were equal to English ivy grown alone (Table XV). English ivy grown with redbud produced root weights and top and root visual grades equal to English ivy grown alone. Only top weight of English ivy was restricted when grown in combination with redbud.

Bald cypress had mixed effects on English ivy. Both top weight and top visual grade of English ivy was reduced by cypress; however, both root weight and root visual grade were equal to English ivy grown alone.

Cottonwood and maple when combined with English ivy severely restricted all growth parameters. Elm when combined with English ivy restricted all growth parameters

TABLE XIV

EFFECTS OF TREES ON VINCA MAJOR

Vinca Major	Control	Cypress	Elm	Pine	CW	Maple	Redbud
Top Weight	230.1[w] d[x]	181.2 c	140.1 b	228.1 d	71.6 a	193.4 cd	204 cd
Root Weight	154.4 d	87.7 b	49.6 a	114.2 c	31.5 a	110.1 c	77.2 b
Visual Grade Tops	7.6 c	6.9 c	4.6 b	6.6 c	1.7 a	5.9 bc	6.9 c
Visual Grade Roots	8.7 e	6.5 d	2.6 b	8.1 e	1.4 a	6.1 d	4.5 c

[w]Numbers are means of 6 replications for each treatment
[x]Values in rows followed by the same letter are not significantly different at the 5% level

TABLE XV

EFFECTS OF TREES ON ENGLISH IVY

English Ivy	Control	Cypress	Elm	Pine	CW	Maple	Redbud
Top Weight	163.5[w] c[x]	98.1 ab	105.1 b	133.4 bc	56.7 a	119.0 b	116.5 b
Root Weight	72.1 bc	66.7 bc	60 ab	76.5 c	47.4 a	47.2 a	67.2 bc
Visual Grade Tops	8.5 d	6.5 bc	6.4 bc	8.0 cd	3.7 a	5.5 b	6.9 bcd
Visual Grade Roots	7.5 c	6.5 bc	5.6 b	6.2 bc	3.9 a	4.1 a	6.5 bc

[w]Numbers are means of 6 replications for each treatment
[x]Values in rows followed by the same letter are not significantly different at the 5% level

except for English ivy root weights.

Evergreen Euonymus

Euonymus showed compatible relationships with most tree species used. Euonymus combined with pine, maple and redbud yielded top and root weights and top and root visual grades equal to euonymus grown alone (Table XVI). When cypress was combined with euonymus, only the visual grade of euonymus roots was restricted.

Elm, an intermediate in its effects on euonymus, restricted top weight and root visual grade. At the same time, euonymus with elm produced root weights and top visual grades equal to euonymus grown alone.

Cottonwood, in combination with euonymus severely restricted all growth parameters of euonymus.

Liriope

Maple was the most compatible tree species with liriope. Top weights and top and root visual grades were equal to liriope grown alone (Table XVII). Only the root weights of liriope were restricted when combined with maple.

Cypress restricted liriope top weight and the root visual grade; however, liriope root weights and top visual grades were unaffected. Pine restricted the root weight and and root visual grade of liriope; however the top weight and the top visual grade of liriope were not affected.

TABLE XVI

EFFECTS OF TREES ON EVERGREEN EUONYMUS

Euonymus	Control	Cypress	Elm	Pine	CW	Maple	Redbud
Top Weight	87.8[w] cd[x]	76.8 bcd	69.6 b	77.2 bcd	42.25 a	92.75 d	73.6 bc
Root Weight	84.5 b	80.5 b	80.8 b	77.5 b	50.5 a	93.9 b	81.0 b
Visual Grade Tops	7.6 b	7.0 b	6.5 b	7.2 b	3.4 a	7.5 b	7.2 b
Visual Grade Roots	8.1 d	6.6 bc	5.7 ab	6.9 bcd	4.7 a	7.5 cd	6.7 bcd

[w]Numbers are means of 6 replications for each treatment
[x]Values in rows followed by the same letter are not significantly different at the 5% level

TABLE XVII

EFFECTS OF TREES ON LIRIOPE

Liriope	Control	Cypress	Elm	Pine	CW	Maple	Redbud
Top Weight	106.6[w] c[x]	87.7 b	85.3 b	113.4 c	43.0 a	106.7 c	82.6 b
Root Weight	230.6 d	218.4 d	164.9 bc	180.1 c	95.2 a	185.7 c	149.7 b
Visual Grade Tops	9.1 b	8.0 b	8.1 b	9.1 b	4.3 a	9.1 b	8.2 b
Visual Grade Roots	10.0 d	6.6 b	6.9 bc	7.7 c	4.5 a	9.2 d	7.1 bc

[w] Numbers are means of 6 replications for each treatment
[x] Values in rows followed by the same letter are not significantly different at the 5% level

Cottonwood severely restricted all growth parameters of liriope. However, elm and redbud did not restrict visual grades of liriope. Top and root weight and visual grade of liriope roots were restricted when liriope was combined with elm and redbud.

Pachysandra

Growth of pachysandra was unaffected when grown in combination with either pine, elm, cypress or redbud (Table XVIII). Pachysandra combined with maple showed a slight restriction in the root visual grade. Pachysandra top and root weight and top visual grade were unaffected by the presence of maple.

Cottonwood severely restricted growth of pachysandra.

Mondo Grass

Trees were either compatible with mondo grass or they severely restricted its growth. Mondo grass combined with pine and maple produced top and root weights and top and root visual grades equal to mondo grass growing alone (Table XIX).

Cottonwood, cypress and elm with mondo grass severely restricted all growth parameters. Mondo grass with redbud produced top weights equal to mondo grass growing alone but root weights and top and root visual grades of mondo grass were restricted.

TABLE XVIII

EFFECTS OF TREES ON PACHYSANDRA

Pachysandra	Control	Cypress	Elm	Pine	CW	Maple	Redbud
Top Weight	19.9[w] ab[x]	23.1 ab	24.2 bc	30.5 c	16.5 a	21.1 ab	18.1 ab
Root Weight	22.4 b	21.7 b	22.2 b	32.0 c	13.2 a	17.7 ab	21.1 b
Visual Grade Tops	6.4 b	6.7 bc	6.1 b	8.3 c	3.1 a	6.0 b	5.4 b
Visual Grade Roots	8.6 cd	7.9 bcd	7.7 bcd	9.4 d	3.1 a	6.5 b	7.0 bc

[w]Numbers are means of 6 replications for each treatment
[x]Values in rows followed by the same letter are not significantly different at the 5% level

TABLE XIX

EFFECTS OF TREES ON MONDO GRASS

Mondo Grass	Control	Cypress	Elm	Pine	CW	Maple	Redbud
Top Weight	34.5[w] d[x]	21.7 b	27.4 c	32.5 d	15.9 a	31.6 cd	33.2 d
Root Weight	93.5 d	74.0 bc	66.4 b	95.0 d	51.6 a	85.1 cd	67.2 b
Visual Grade Tops	8.5 c	6.3 b	7.0 b	9.0 c	4.5 a	8.5 c	6.6 b
Visual Grade Roots	9.0 c	7.2 b	4.7 a	8.9 c	5.2 a	8.2 bc	7.1 b

[w]Numbers are means of 6 replications for each treatment

[x]Values in rows followed by the same letter are not significantly different at the 5% level

Table XX is a summation of the information presented in Effects of Trees on Ground Covers.

Discussion

Before making recommendations as to types of ground covers and trees that are compatible in a landscape, it is necessary to compare both sides of the relationship (i.e., effects of tree on ground cover and effects of ground cover on tree). Since trees are long term elements in a landscape and play a major role in creating and modifying the immediate environment, it is felt that the growth of the tree should receive a higher priority than the growth of the ground cover.

Height of trees and top weights of ground covers were judged the parameters most useful in reflecting plant responses. These parameters were used to create two-dimensional graphs reflecting tree-ground cover relationship (Figure 2 and Figure 3).

By comparing the two figures, Figure 2 and Figure 3, with Tables III through XX, the following relationships between trees and ground covers appear most useful.

Cottonwood was by far the most severe competitor of the six tree species used. Height of cottonwood was actually stimulated when grown in the presence of most ground covers (Figure 3). However, considering effects of trees on ground covers, it becomes apparent that the stimulated height of cottonwood was at the expense of ground cover top weight

TABLE XX

SUMMARY OF THE EFFECTS OF TREES ON GROUND COVERS

Bermudagrass

Compatible	Non-compatible
1. Pine	1. Cottonwood
2. Cypress	2. Elm
	3. Maple
	4. Redbud

Fescue

Compatible	Non-compatible
1. Pine	1. Cottonwood
2. Maple	2. Elm
3. Redbud	3. Cypress

Dwarf Bamboo

Compatible	Non-compatible
1. Pine	1. Cottonwood
	2. Elm
	3. Cypress
	4. Maple

Vinca minor

Compatible	Non-compatible
1. Pine	1. Cottonwood
	2. Elm
	3. Cypress
	4. Redbud

Vinca major

Compatible	Non-compatible
1. Pine	1. Cottonwood
2. Redbud	2. Elm
3. Maple	3. Cypress

TABLE XX (Continued)

English Ivy

Compatible	Non-compatible
1. Pine	1. Cottonwood
2. Redbud	2. Maple
3. Cypress	3. Elm

Euonymus

Compatible	Non-compatible
1. Maple	1. Cottonwood
2. Pine	2. Elm
3. Redbud	
4. Cypress	

Liriope

Compatible	Non-compatible
1. Maple	1. Cottonwood
2. Pine	2. Redbud
3. Cypress	3. Elm

Pachysandra

Compatible	Non-compatible
1. Pine	1. Cottonwood
2. Elm	
3. Cypress	
4. Redbud	
5. Maple	

Mondo Grass

Compatible	Non-compatible
1. Pine	1. Cottonwood
2. Maple	2. Cypress
	3. Elm
	4. Redbud

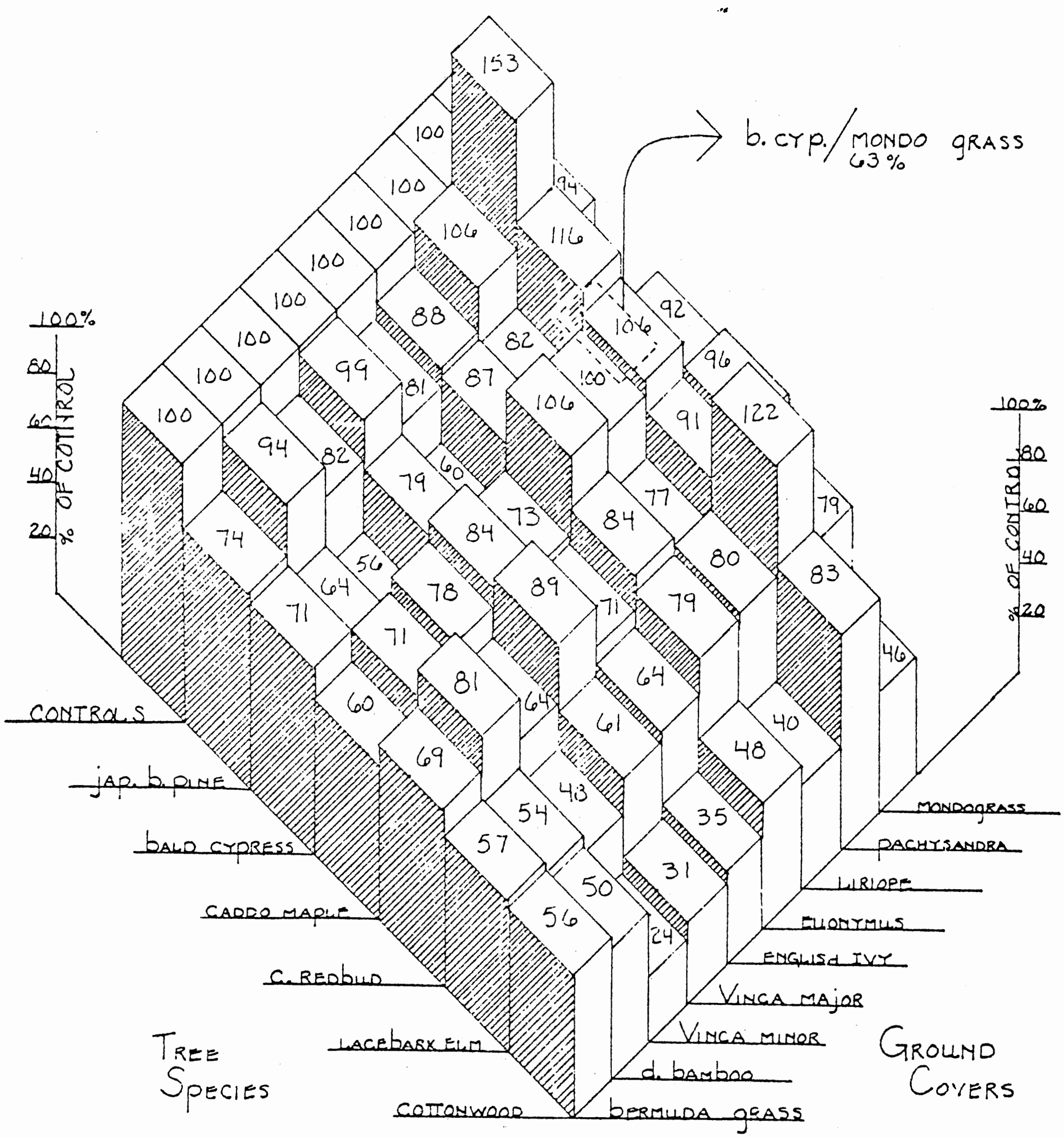

Figure 2. Effects of Trees on Top Weights of Ground Cover

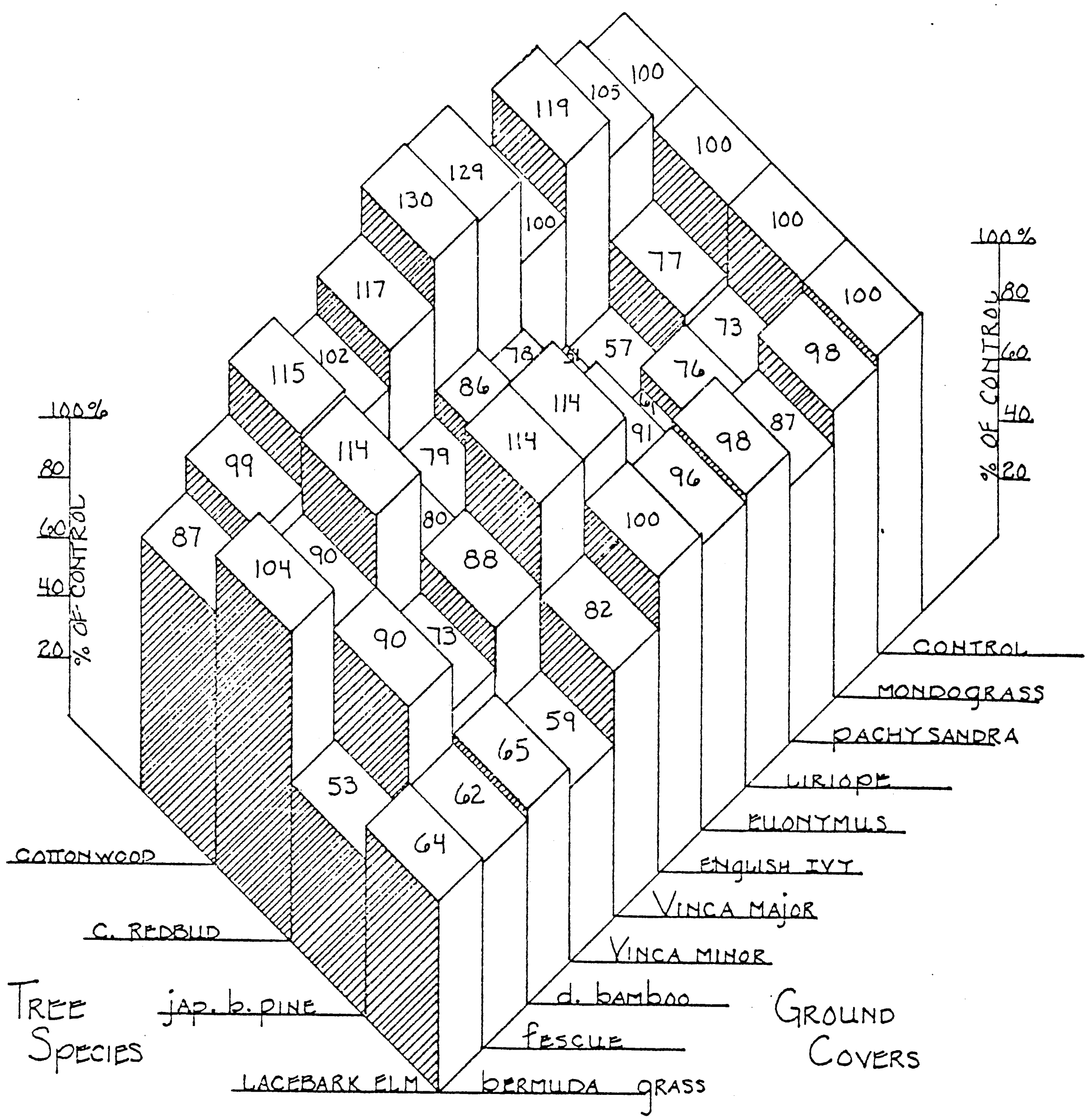

Figure 3. Effects of Ground Cover on Height of Tree

(Figure 2). This is similar to a parasitic type relationship, where individuals of one species benefits (cottonwoods), while individuals of another species (ground covers) are harmed. Other trees ranked succeedingly in their degree of competitiveness are lacebark elm, bald cypress, redbud, maple and pine.

Pine seemed compatible with most gound covers used. Pachysandra, combined with pine, actually grew 53% better than pachysandra grown alone (Figure 2). However, looking at effects of ground covers on height of pine, this additional growth of pachysandra was at the expense of pine height, which was reduced by 24% over pines grown alone (Figure 3).

Ground covers as a group did not restrict tree performance. Instead, relations seemed to be more species specific. For example, Japanese black pine and lacebark elm were reduced in height 47% and 36%, respectively, by bermudagrass (Figure 3). Cottonwood was slightly restricted (13%), but redbud was actually taller when bermudagrass was present (Figure 3).

The effects of liriope on height of tree seems to show another species specific relationship (Figure 3). The elm and cottonwood were virtually unaffected by the presence of liriope. However, redbud and and pine were restricted 49% and 39% respectively. Looking at the opposite side of the effects, liriope top weight was restricted by 23% and 60% when combined with redbud and cottonwood. However, pines actually promoted a slight (6%) increase in liriope top weight. Neither cottonwood, redbud or pine in combination with liriope would be desirable in a landscape because all are detrimental to the growth and vigor of the tree.

In order to obtain an understanding of the relationships that exist between the 6 tree species and the 10 ground covers used, all 9 growth parameters must be combined and compared (Tables III through XX). Since trees are much more likely to be the established plant in the landscape, recommendations from this study are for ground covers that appear to be most compatible with the six tree species used (Table XXI). Growth of some of the ground covers was restricted; however, visual quality remained acceptable.

There were many instances where the tree did not restrict the visual quality of the ground cover, but the ground cover stunted the tree (Figures 4 through 9). This information may be applicable in a landscape where large, existing, mature trees dominate.

For example in Figure 4, pachysandra when grown in combination with .bald cypress, produced 16% more top weight than pachysandra grown alone. However, bald cypress height was restricted by 15% when compared to bald cypress control. If the same conditions existed in a landscape environment where pachysandra was planted beneath a large mature bald cypress and approximately the same results occurred, the 15% restricted growth of bald cypress would be acceptable because of the successful growth and establishment of the ground cover.

TABLE XXI

GROUND COVER RECOMMENDATIONS FOR SPECIFIC TREES

Compatible	Non-compatible
Bald Cypress	
1. English Ivy	1. Dwarf bamboo
2. Pachysandra	2. Bermudagrass
Lacebark Elm	
1. English Ivy	1. Bermudagrass
2. Pachysandra	2. Liriope
3. Euonymus	
Japanese Black Pine	
1. Vinca major	1. Bermudagrass
2. English Ivy	2. Liriope
3. Pachysandra	
4. Euonymus	
Cottonwood	
1. None	1. Bermudagrass
	2. Liriope
	3. English Ivy
	4. Fescue
Maple	
1. Euonymus	1. Bermudagrass
2. Pachysandra	2. Liriope

Note: under Japanese Black Pine the heading is printed "Non-compatbile".

TABLE XXI (Continued)

Redbud	
Compatible	Non-compatible
1. Fescue	1. Liriope
2. Vinca major	2. Vinca minor
3. Bermudagrass	
4. Dwarf bamboo	

In Figures 5 and 6 the same occurrence results between lacebark elm and pachysandra. Figure 6 also shows a reversed relationship. Looking at Japanese black pine and English ivy a 14% increase is recorded for pine when grown in the presence of English ivy; but, English ivy is reduced by 19% when compared to its control. Knowing the vigorous density of a properly located English ivy plant in the landscape, a 19% reduction in top weight would barely be visible and so acceptable. Plus, a slight advantage might be gained in establishing a newly planted pine.

Figures 7, 8 and 9 show many such relationships between trees and ground covers. In order to best utilize these results, a thorough analysis must first be made of each landscape environment, plants should be chosen that are adaptable to the site and plant combinations selected only after considering the minimal, but acceptable, visual quality of the plants in the landscape.

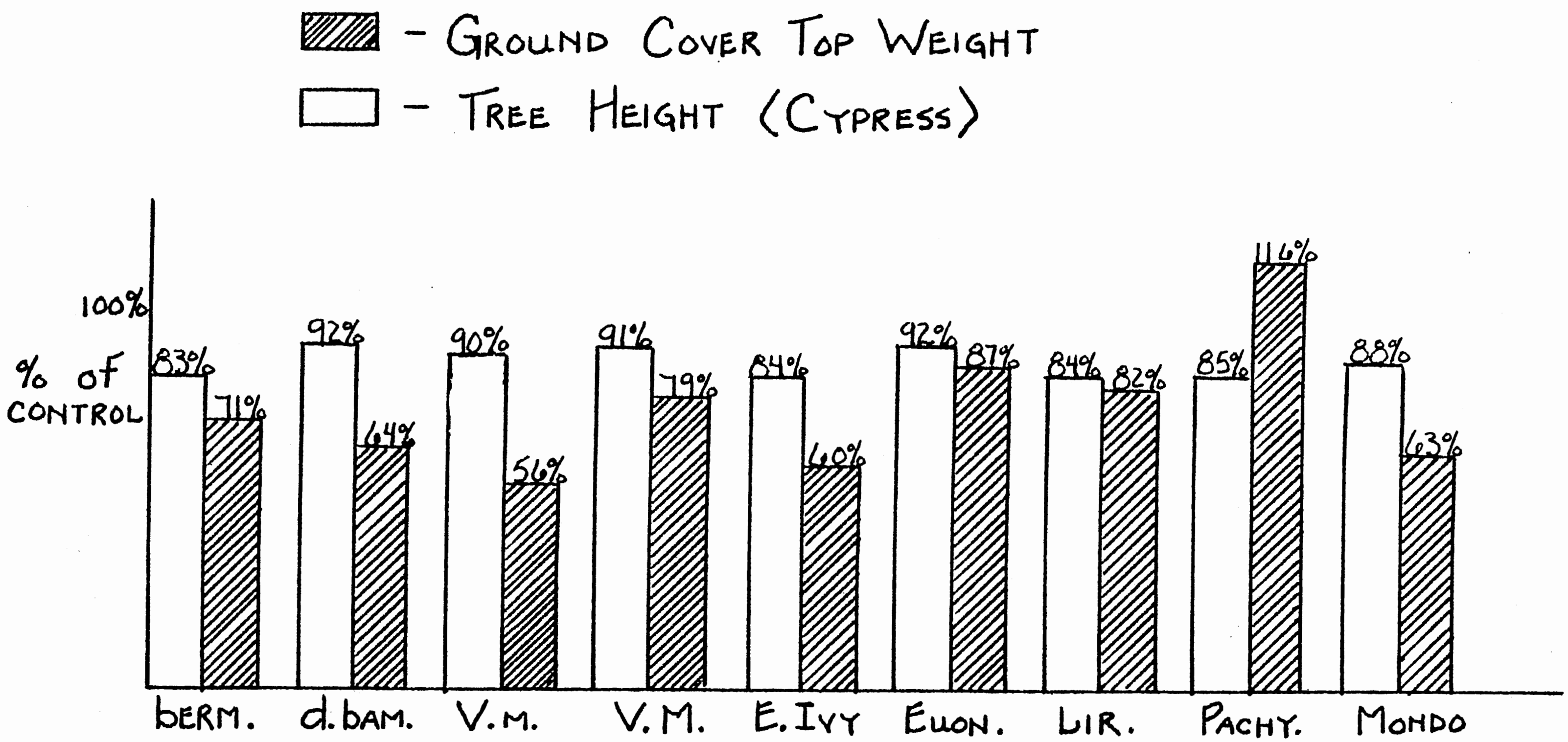

Figure 4. Relationships between Bald Cypress Height and Ground Cover Top Weight

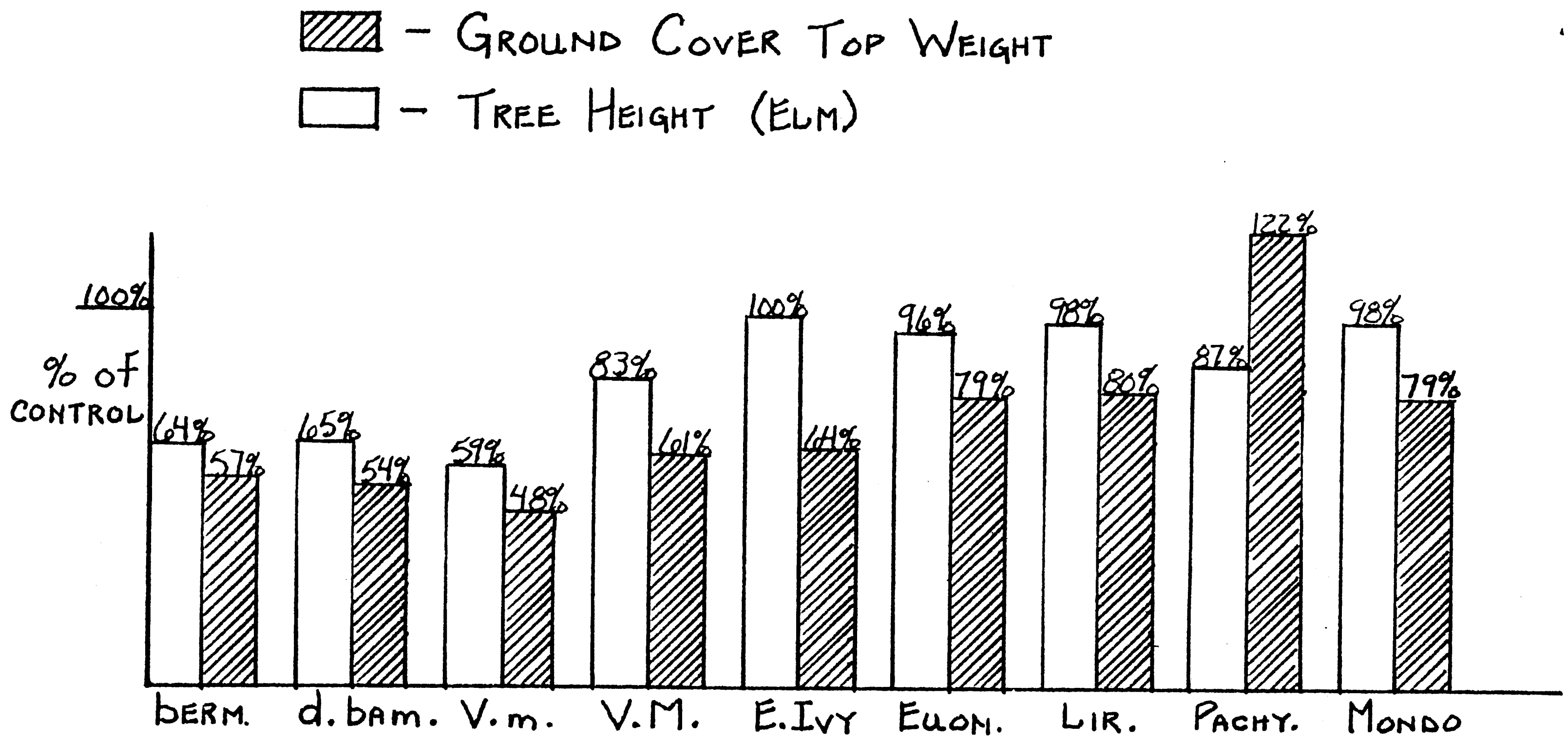

Figure 5. Relationships between Elm Height and Ground Cover Top Weight

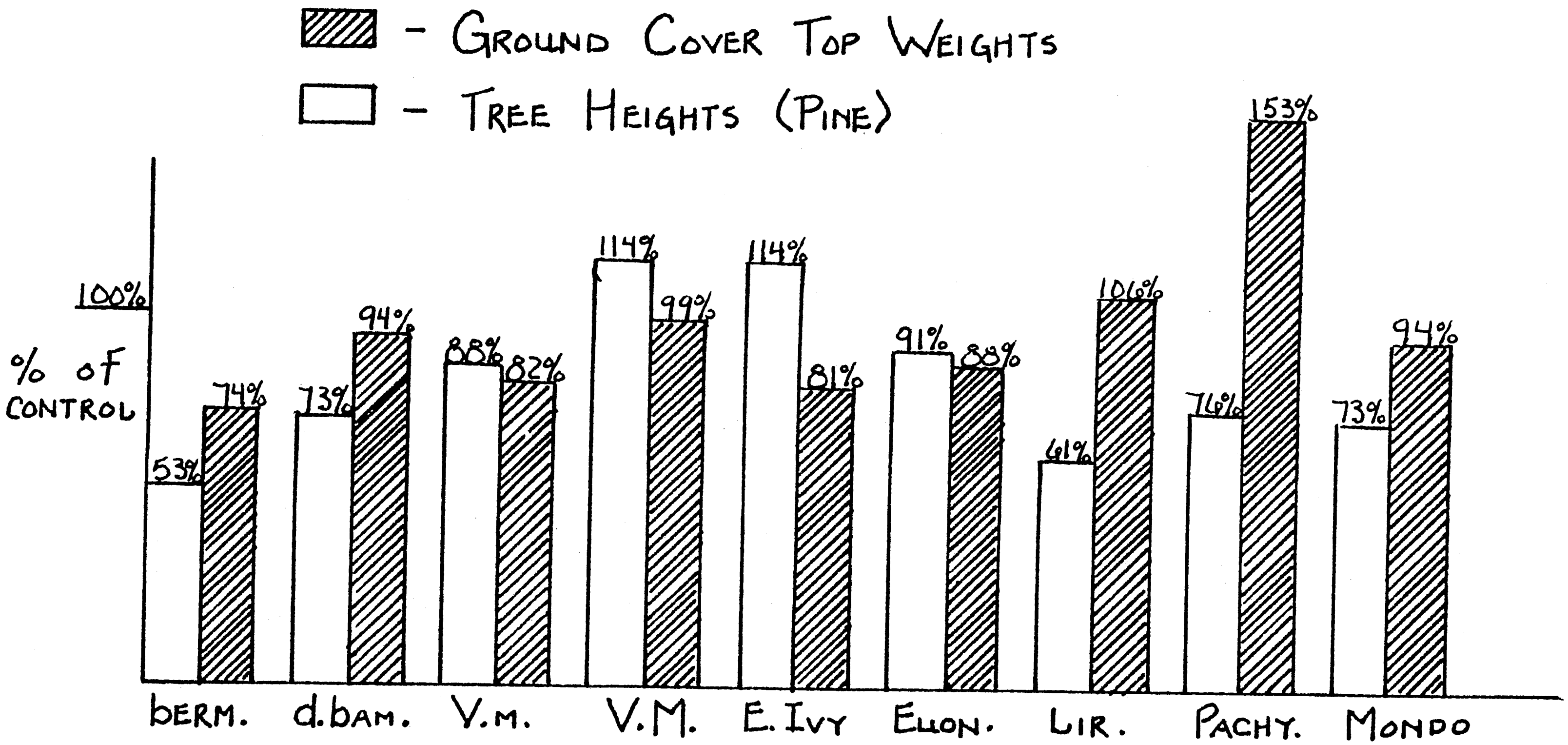

Figure 6. Relationships between Pine Height and Ground Cover Top Weight

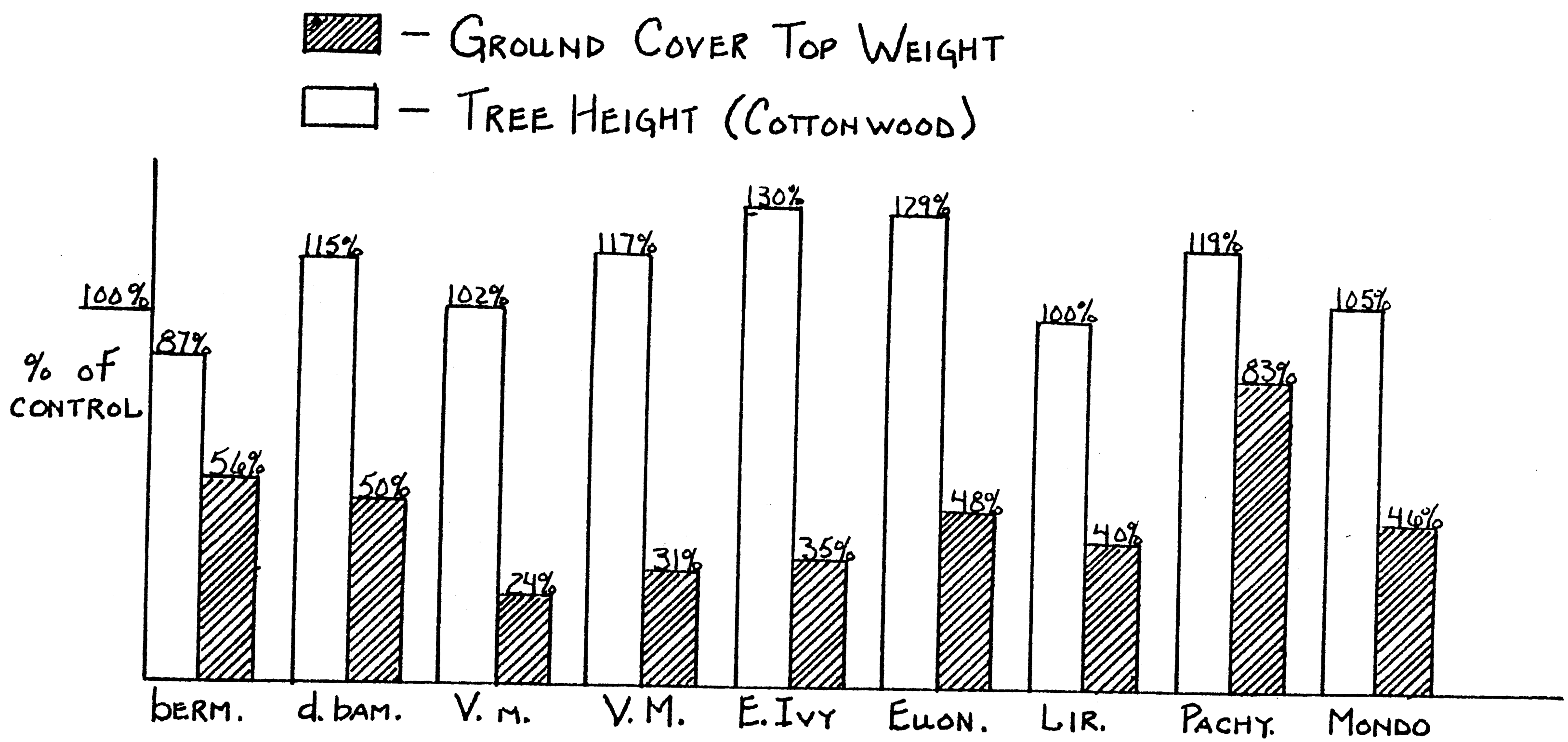

Figure 7. Relationships between Cottonwood Height and Ground Cover Top Weight

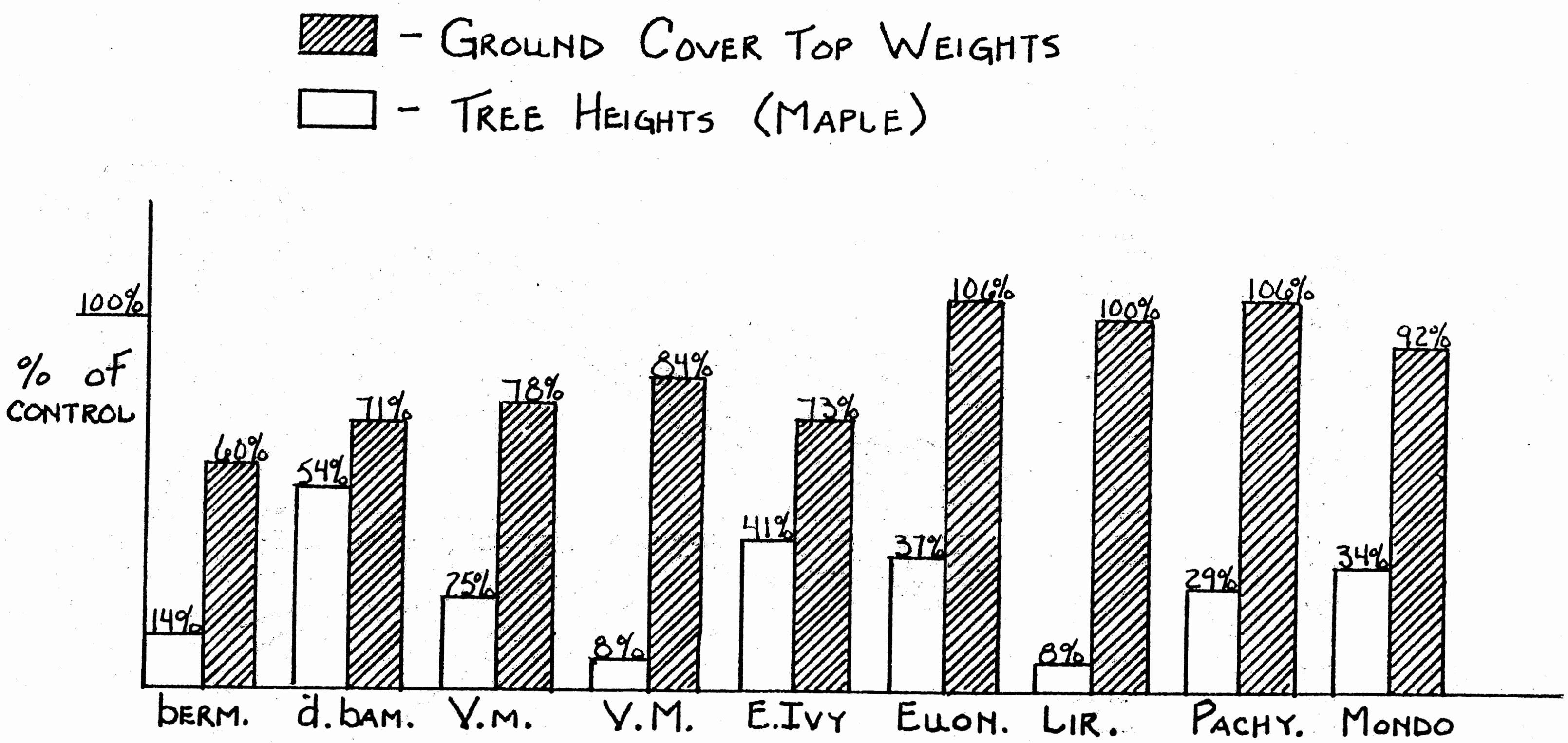

Figure 8. Relationships between Maple Height and Ground Cover Top Weight

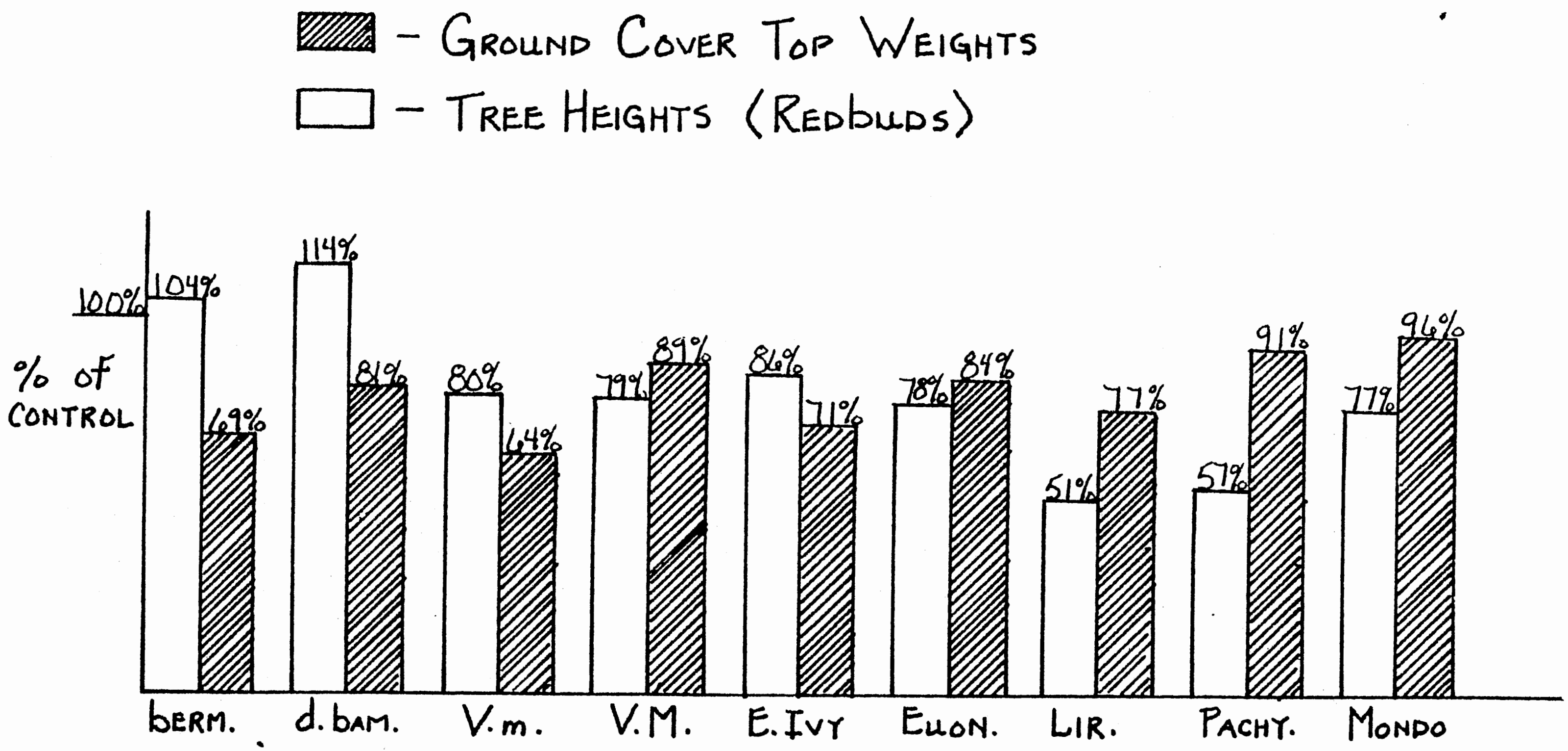

Figure 8. Relationships between Maple Height and Ground Cover Top Weight

Some of the results are confusing and hard to interpelate. For example, why could Chinese redbud withstand competition from bermudagrass when all other tree species used were restricted, some of which were much more vigorous growers (elm, cypress, cottonwood)? Is it related to the fact that redbuds, being a member of the legume family, are able to fix or tie up nitrogen in the nodules of their root system and thus reduce the competition between redbud and bermudagrass for nitrogen? Or, could the large leaf surface area of the redbud have restricted sufficient amounts of light to have reduced the vigor of sun-loving bermudagrass? A further example is cottonwood which severely restricted growth of all ground covers except pachysandra. Why was pachysandra able to withstand and compete with cottonwood when all other ground covers failed?

This study obviously raised more questions than it answered, but, there must be a beginning point if relationships between trees and ground covers, the two most functional elements in a landscape, are to ever be understood and utilized.

CHAPTER V

SUMMARY AND CONCLUSIONS

This is one of the first studies to approach the problems of relationships between plants in a man-managed environment. The results described are preliminary at best. More studies are needed in both containers and the landscape to determine tree-ground cover relationships best suited to a particular environment.

This study was not designed to test the theories of allelopathy or symbiosis. Plants would have to be grown for a much longer period of time, and additional studies conducted (bio-assays) in order to determine if such plant relationships exist. The literature strongly suggests that plants do secrete chemicals into the environment that have an inhibiting or stimulating effect on adjacent plants.

It would be interesting to study the relationships of trees and ground covers in a rhizotron. This would allow a study of the active periods of growth of each of the two plants involved, and through close observations, a better understanding could be gained of the interactions that occur when two opposing roots come in close contact with one another. It would also allow the study to be conducted in a field soil without actually disturbing the root systems of the plants involved. Unfortunately, a system of this type would be very expensive to set up and manage.

Many more studies need to be conducted before a realistic understanding of the relationships between two plants in a landscape environment exists. Through continued research, an understanding of plant relationships can be obtained which may reduce landscape maintenance and cost of plant replacements while improving plant esthetics in the landscape.

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VITA 2

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