RESPONSE OF ULMUS AMERICANA AND U. PUMILA TO WINTER STORAGE

by

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INTRODUCTION

Status of Nursery Stock Storage

Progress in nursery stock storage has not kept pace with that of other industries using storage facilities. Most of the developments in the nursery industry have been the result of the application of a building material, piece of equipment, or a technique used successfully by some other industry.

Techniques for processing and handling nursery stock have changed very little over the last fifty years, in spite of the development of defoliants, anti-desiccants, and plastics. Recently, however, there has been a revival of interest in methods of storage construction and materials, as well as in the procedures of digging, storing, and packaging of ornamental plant products.

Nurserymen have long been interested in the procedures for handling plant material through the winter months. During this storage sequence, the principle objective is to maintain the stock in a viable, dormant condition, and free from molds. The ultimate concern is the response of the plant after storage, purchase, and planting by the customer.

Operations such as pruning, application of fungicides, prepackaging, and the use of pallets, conveyors, and packaging machines might lead to increased efficiency of nursery operations. This increased efficiency would directly benefit

the consumer not only by price reduction but also by quality improvement.

The wholesale value of deciduous shade trees grown in ten leading states producing nursery stock was 6.1 million dollars in 1958. In 1959, a similar survey covering these same states showed that the inventory was 7.3 million dollars, or an increase of 17 per cent over the previous year (54). According to most wholesale nursery catalogues, the Ulmus genus comprises ten per cent of the total deciduous shade tree listings. Without doubt, the total percentage of sales volume is much higher than this estimate indicates.

Purpose of the Study

In recent years the sale of Ulmus americana, the American elm, has decreased. This is a trend brought about by the susceptibility of the species to the Dutch elm disease. Ulmus pumila, the Siberian elm, on the other hand appears to be one of the most resistant of the elm species to this disease. Several new hybrid elms also appear to be resistant to this fungus (55). As a result, emphasis has been placed on the production and sale of these resistant types. The hybrid elms are commonly propagated by either budding or grafting on seedlings of Ulmus pumila. Nurserymen have observed that Ulmus pumila is more difficult to store than the American elm. Ulmus pumila is thought to break dormancy

early, relative to Ulmus americana, and with a larger proportion of sprouts.

Studies have established that seedlings of the Siberian elm are not tolerant of frost or freezing temperatures experienced during late fall digging operations, or during the holding, shipping, and planting sequence (7, 58). The American elm is quite resistant to such exposure (7), and is classified as a Zone II plant (45). This lack of resistance of the Siberian elm to freezing injury may contribute to its poor storage performance. Although both species of elm may be removed from winter storage apparently in a similar dormant condition, growth responses after planting may be quite variable. For example, spring growth may be negligible, even though the stem portions remain green for an extended period of time. Shoots may be produced which are weak and poorly colored. Some develop into attractive, healthy young trees. There are no satisfactory explanations for this variance in response.

The purpose of this study was to establish the responses of Ulmus americana and Ulmus pumila under known laboratory conditions. After establishing morphological and physiological characteristics of the two species, it was the further purpose of this study to investigate the effects of various root and stem packaging treatments as they in turn were related to storage and field performance.

LITERATURE REVIEW

Introduction

The importance of the winter storage of ornamental plants has been outlined by Bailey (1), Cooper (8), Kains and McQueston (17), and by Mahlstede and Fletcher (25). Although there are numerous reasons why nursery stock is dug in the fall in the northern part of the United States (6, 9, 10, 11, 13, 14, 27, 28, 40, and 50), these generally fall into two major categories. They include: 1) adaptation of plants to fall digging, and 2) economic factors, such as labor, distribution, grading, propagation, and reduction in losses due to severe winter temperatures or rodent damage.

Treatment and Response of Stored Stock

Successful storage begins with plants still growing in the field (53). Growth of plants prior to storage is of the utmost importance and will determine the eventual performance of stored material. Factors contributing to the successful storage would include hardening-off of plant materials, preparations prior to and including digging, the care from digging until final placement in storage, and storage management.

Hardening-off of plant materials

Any process, natural or artificial, which will check the growth of a plant without reducing photosynthesis will increase differentiation processes. Differentiation results in a general thickening of the cell walls, development of protoplasm resistant to freezing, and an overall maturity of the plant tissues.

The nurseryman is able to modify his cultural practices to bring about conditions that are favorable for differentiation. These might include the reduction of the water supply if irrigation is practiced, withholding nitrogenous fertilizer applications, and undercutting roots of the plants. Little can be done to insure maturation, except to withhold applications of high analysis nitrogen fertilizer after the middle part of the summer, and to cease cultivation during late summer (52). These practices tend to discourage new, succulent growth toward the end of the growing season. Such growth is not adapted for storage due to its susceptibility to freezing injury and attack by pathogenic organisms (28).

Defoliation, maturity, and digging stock for storage

Pre-storage defoliation of nursery stock is an important factor contributing to the successful storage of nursery stock. Defoliation can be natural or induced by the use of chemicals or mechanical devices. The degree of defoliation

obtained from chemicals will vary according to the plant species, kind and concentration of defoliant, and the time of application (4). There is general agreement that defoliation becomes less difficult as plants become mature. Several other methods have been used to defoliate nursery stock (46). These include: 1) partial lifting of plants by undercutting several weeks prior to digging, 2) use of sheep to remove foliage, 3) use of ethylene gas, and 4) mechanical stripping. Only partial defoliation results from these methods and consequently, chemical methods are still considered to be the best means for removing the foliage from deciduous nursery stock. Another method of defoliation has been termed "sweating". This consists of loose stacking and watering of foliated plants in temporary ricks in common storage. The rapid respiration and/or fermentation processes increase temperature and humidity which results in leaf abscission (25). Although successful, this method is not practical for large quantities of stock since the final appearance of the product is not enhanced and the attendant heat buildup in the storage unit creates a problem in units not equipped with mechanical refrigeration (41). In addition, the presence of dead or rotting leaves in a storage, when moistened, serve as excellent hosts for the development and growth of saprophytic organisms (20). Although defoliation is important, premature defoliation may result in poor or inferior

stock upon completion of storage.

Oatman (38), states that digging in preparation for storage should begin after the plants have matured and dropped their foliage. Fully matured plants contain more stored food and water which will result in better storage performance (27, 52). Damage of nursery stock by cold temperatures is in direct proportion to the earliness and degree of defoliation (52). Tukey also stresses the importance of keeping plants in a good growing condition and free from foliar diseases or disorders which might prematurely defoliate the crop (52). The subject of the importance of maturity has been stressed by other workers (3, 14, 17, 18, 22, 23, 28, and 32). Lyle[1] conducted tests with roses and found that starch tests provide a quick method for determining the relative maturity of a plant. The sections tested are rated according to the degree of staining by an iodine solution. However, this rating is relative and correlations between the degree of staining and subsequent performance in storage pertain to only one crop in a given environment.

The age of the crop will influence the time of removal from the field (25). Older and more mature deciduous plant

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[1]Lyle, E. W. Tyler, Texas. Texas Rose Research Foundation, Inc. Information on staining techniques as related to maturity tests. Private communication. 1958.

materials generally defoliate earlier than the more rapidly growing, younger stock. As a result, these older specimens may be dug earlier. Removal of stock in quantity should begin soon after the first killing frost. Premature digging results in decreased growth the following season, as does premature defoliation. To illustrate this point, Mahlstede (22), conducted experiments with Althea rosea to determine the effect of digging on maturity and keeping ability in storage. The author stated that early digging impaired the keeping quality and reduced field stands the following season. Following the digging operation, the roots should be kept constantly moist (2, 15).

Pruning

Little work has been done on pruning immediately prior to storage. It is generally thought that pruning or trimming required for stock that is to be dug in the fall should be performed early in the growing season, not immediately prior to or following the digging operation. Tukey and Brase (53), conducted pruning tests on roses and two-year old cherry trees which resulted in die-back in storage and decreased growth the following spring.

Janne and Chadwick (16), made observations on the field response of roses that were pruned before and after storage. Roses pruned to ten inches above the bud union before storage

showed less mold and storage injury and produced more flowers per plant than did the check or other pre-storage pruning treatments. Pruning canes to a length of five to six inches after storage did not decrease flowering. These pruning responses indicated that satisfactory performance is favored by either little or no pruning before storage.

Waxing

The use of wax to prevent desiccation of certain plant products dates back to the first century A.D. In a translation of the writings of Pliny, by Bostock and Riley (42, pp. 303-307), procedures were outlined for coating choice apples with plaster or wax to prevent drying and to aid in the retention of characteristic flavor. Much information now exists concerning the effects of various protective coatings in extending the storage life of fruits and vegetables. Many authors agree that waxing prevents desiccation (2, 13, 21, 30, 31, 33, 34, 35, 36, 37, 48, and 51), in addition to other functions. Most of the literature lacks substantial data to support the conclusion. However, research by Neilson (35), and Toy (51), presented more conclusive data showing the role of wax in retarding moisture loss from plant tissues.

Dr. Robert T. Morris is given credit for the proposal and employment of the use of wax on propagation material (17). It was concluded that wax apparently prevents drying

and conserves vitality, thereby favoring prompt growth after planting. Morris (33), observed that scions shipped long distances by mail were usually found to be either too dry or too moist. Generally, scionwood arrived in a desiccated condition. The author noted from limited experiments that scions completely covered with wax yielded favorable results. Results were also improved when waxing was restricted only to the cut ends of the scions. The successful use of wax for preventing desiccation of grafted apple scions was also reported by Morris (33). In papers by Neilson (34, 35, 36, and 37), the author discussed the important effects of waxing on nursery stock. In a laboratory experiment, hot paraffin brushed on sections of willow stems reduced moisture loss by 80 per cent after 24 hours, in comparison to untreated sections. This difference in weight loss was reduced to 45 per cent by the end of 28 days (35).

Neilson (37), later reported that the application of liquid waxes to large trees before planting prevented desiccation and resulted in superior field performance. Miller et al. (31), stated that by 1937, waxing had become a common treatment for nursery stock. This wax not only served to prevent mold and desiccation in storage, but also retarded desiccation until the root systems had become well established after transplanting. Miller et al. (30), reported on various aspects of wax development and noted that applications of wax

emulsions markedly reduced transpiration without completely inhibiting respiration. Neilson (34, 35), reported that waxing did not hinder respiration.

Tey (51), studied the effects of paraffin waxes on the growth and physiology of rose canes. In this experiment tests were made on the effect of waxing on stem portions of a number of different plant materials. The plant materials used included Rosa hybrida variety Crimson Glory, Ligustrum amurense, and Hibiscus syriacus. Each species group was given three treatments. The first group was dipped and completely covered with wax. The second group involved dipping the stem ends in wax, and the third group was left untreated. Results showed that all of the untreated groups lost weight very rapidly. Coating the ends resulted in a significant reduction in moisture loss from althea, although little or no effect was found in tests with rose sections. The response of sections of Ligustrum amurense was intermediate between these two extremes. Complete coverage of the entire section of all the plant materials appreciably reduced moisture loss.

Packing materials

Studies conducted in 1905, by Cooper (9), indicated that there was some doubt whether the use of packing materials around the roots of nursery stock in storage was of any benefit. Some growers reported good results using no packing

material. Today, however, the majority of nurserymen use some sort of packing material around the roots of plant materials in storage. The most common packing material in use is sphagnum moss. Other popular media include shingle-tow, shavings, granulated peat, sawdust, and/or mixtures of these materials. Packing consists of the placement of a suitable, moistened material around the roots, thereby preventing undue desiccation.

Watering

The amount of water used, and the regularity with which it is applied, depends upon several factors. Among these factors are temperature, humidity, packing medium employed, storage construction, and the efficiency of the workers in charge of watering.

Maintenance of temperature

There is general agreement among authors that nursery stock is stored most satisfactorily at temperatures approaching the freezing point of water. Bailey (1), reported that the best results were obtained at temperatures from 28-34°F. Cooper (8, 9), Yerkes and Gardner (57), Anonymous (6, 44), and Kains and McQueston (17), maintain that a range of 28-30°F is optimum. A temperature range of 30-32°F was suggested by Laurie and Chadwick (18), Peteran and Porterfield

(40), Janne and Chadwick (16), and Haller (14). Janne and Chadwick (16), and Deffenbacher and Wright (10), also showed satisfactory results with temperatures as high as 35°F. Injury may result if the selected temperature is not maintained fairly constant. Fluctuating temperatures, for any extended period of time, cause drying, especially if the upper limit is too high.

Although 32°F is the freezing point of pure water, a lower temperature appears to be required to crystallize water in plant tissue. Temperatures below 28°F must be maintained in order to bring about crystallization (40). The actual freezing point of plant tissue is seldom below 23°F (29).

Humidity

Maintenance of a high relative humidity in storage is strongly advised. Relative humidities in the range of 90-95 per cent are considered optimum (10, 24, 44, and 53). Although good results have been reported at 80-90 per cent (6), humidity less than 90 per cent often causes the dehydration of roots and stems.

Saprophytic organisms

The appearance of saprophytic organisms is favored by an excessive amount of moisture (20), by temperatures maintained above 32°F (17), by the presence of dead leaves in

the storage unit (20), by the presence of damaged plants (25), or by plants which are not fully mature (52). Maintenance of a uniform temperature approximating the freezing point and adequate air circulation within the storage generally control these organisms effectively.

Sprouting in storage

The appearance of sprouts on stored material depends upon dormancy characteristics of the material and on the existing temperature and humidity conditions within the storage facility. The length of the rest period varies according to the particular plant type (28). Some plants fulfill their period of rest rapidly and then break dormancy early under favorable environmental conditions. Others are slower to begin sprouting.

Sprouting may be controlled by either the application of chemicals or by controlling the environment. The use of chemicals to delay bud break has given inconsistent results. In most instances, nurserymen have a number of different genera housed in the same storage room. Since each plant type will react differently to the dose of the chemical applied, the problem of application is complicated.

Field response of stored stock

Nursery stock stored through the winter was found to be comparable to freshly dug stock (38, 47), and early growth and survival measurements slightly favored the stored plant material. These differences tended to disappear as the storage period was extended into the late spring (47). More vigorous growth was produced from stored plants than from those dug in the spring (6, 14, and 56). Plants removed from storage produced more even growth and developed more rapidly than under normal conditions (44). Plants that did not sprout in storage produced much greater root growth and top growth with a greater number and improved quality of bloom compared to those which had sprouted in storage (28). Whether or not trees are actually in better condition when they reach the grower after winter storage is a controversial question, since there are so many factors to be considered. However, if results were not satisfactory to the public, nurseries would not practice this method of winter storage (17).

DESICCATION EXPERIMENT

Purpose of the Study

In order to determine rates and amounts of moisture loss for the two species of Ulmus, experiments were conducted prior to storage in which various treatments were applied to root and stem sections.

Because the application of wax to stems of seedling trees was to constitute one of the major treatments of a later experiment, this material was tested in preliminary desiccation studies to determine its effectiveness as an anti-desiccant.

Materials and Method

Seedling plants that had been obtained from a commercial nursery were stored in a common storage for a period of two weeks. Temperatures in this storage averaged 35°F, with a relative humidity between 85-95 per cent. During this holding period it was felt that all plants reached equilibrium with the environment.

Thirty-five stem sections were then cut for each species used. From this number, 24 of the most uniform sections were selected. Six sections were then drawn at random for each of the four groups representing different treatments. Plant parts selected for this experiment were similar in overall

dimensions. Stem sections were 10 cm. in length and averaged .49 cm. in diameter. The size of the exposed surface area of the sections was about 15.7 $cm.^2$. The average weight for the 24 sections of Ulmus americana was 1.142 grams, contrasted to 1.224 grams for an equal number of sections of Ulmus pumila. All cutting and selection of these materials was performed in a walk-in cooler operating at a temperature of 33°F.

The total exposed area for each treatment was as follows: 1) 100 per cent exposure for sections receiving no waxing, 2) 87.5 per cent exposure for sections having only the ends waxed, 3) 2.5 per cent exposure for sections having only the circumference of the stem section waxed, and 4) no exposure for those which were completely waxed.

The roots of both species were treated identically. Each section, which had an average diameter of .51 cm., was cut to a length of 7 cm. This size resulted in an exposed area of approximately 11.5 $cm.^2$. The average weight of the 24 root sections of Ulmus americana was 1.397 grams, while those of Ulmus pumila averaged 1.583 grams. The total exposed area for each root section treatment was: 1) 100 per cent exposure for sections that were not waxed, 2) 88.5 per cent for sections having only the ends waxed, 3) 4.7 per cent exposure for sections having only the circumference of the root section waxed, and 4) no exposure for sections completely

dipped in wax.

The wax used in this study was the common rose bush wax. Wax temperature was held at 167°F during treatment by means of a thermostatically controlled electric water bath heater. The ends of the sections were waxed by dipping to a depth of .5 cm. for a period of two seconds. The epidermis of a section was waxed by covering the cut ends and plunging the section into the wax. If any wax adhered to the cut ends, the section was discarded or used in the group that was to be completely waxed. After the wax treatments had been completed, sections again were weighed. The weight increase was recorded as the amount of wax present upon the section. In all subsequent calculations of weight loss, per cent moisture, or the per cent of dry material, the data were based upon the weight of the specimen prior to waxing.

Sections were then placed on a large sheet of plate glass to insure that moisture loss was due primarily to evaporation. Three times daily, the glass was rotated ninety degrees so that each section would receive as identical an environment as possible. During the entire 21 day period of observation, moisture loss readings were taken at 12 hour intervals. The data obtained were converted to give the percentage moisture loss, based upon a percentage of 100 in the wax free sections. Since the sections used in each treatment were nearly alike, the mean figures for each determina-

tion were used in plotting the curves.

Measurements of the temperature and relative humidity of the laboratory environment were made when weight loss measurements were recorded. The relative humidity was obtained by the use of a motor driven wet and dry bulb psychrometer.

Results and Discussion

The relative humidity ranged from 32-62 per cent, with a mean of 43.0 per cent. Temperatures in the laboratory ranged from 68-79°F with a mean of 73.5°F.

The data presented in the tables and figures were based upon three assumptions: 1) all of the moisture loss was due to evaporation, 2) no moisture was lost by absorption by the glass upon which the sections were supported, and 3) the sections did not absorb any moisture from the supporting plate. Some weight loss could have occurred from increased respiratory activity of the tissues ruptured at the ends of the sections. However, this weight loss would be that of dry matter and not of moisture. The loss of dry matter would be expected to be relatively small, the omission of which would not seriously affect the overall results.

In the final moisture content determinations, it was found that both root and stem sections of Ulmus pumila contained higher percentages of moisture than did those of Ulmus

americana. The moisture content of stem sections of Ulmus pumila averaged 51.45 per cent, compared to 46.33 per cent for Ulmus americana. The average moisture content of Ulmus pumila root sections was 62.62 per cent in contrast to 54.34 per cent for similar root segments of Ulmus americana.

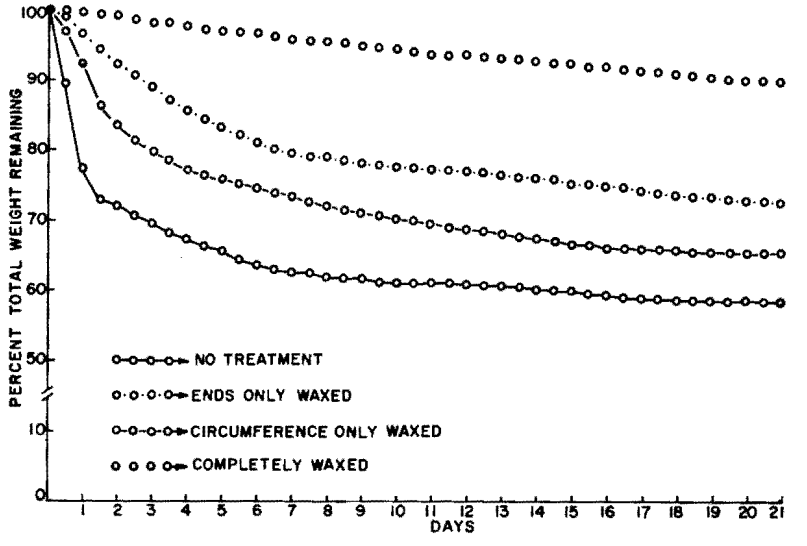
Stem treatments

For both species of Ulmus, similar treatments had similar effects as shown by the data contained in Figures 1 and 2 and Tables 1 and 2. Curves in Figures 1 and 2 show that the groups receiving no wax lost weight very rapidly and gradually approached a constant weight. For both species, three-fourths of their total weight loss had occurred by the third day (Table 1). One-half of the total moisture loss in stem sections of Ulmus americana had occurred in one day, while the same loss from Ulmus pumila sections took one and one-half days.

The group in which only the stem circumference was waxed lost weight more rapidly than did the other waxing treatments (Figures 1 and 2; Table 1). This difference indicated that moisture was lost more rapidly through the epidermis and cuticle. No suberization of the cut ends was observed in this group. Those sections waxed only on the ends lost moisture more rapidly than those entirely waxed. Although a large surface was exposed in this treatment, weight loss

Figure 1. Rate of moisture loss from stem sections of *Ulmus americana*

Figure 2. Rate of moisture loss from stem sections of *Ulmus pumila*


PERCENT TOTAL WEIGHT REMAINING
100
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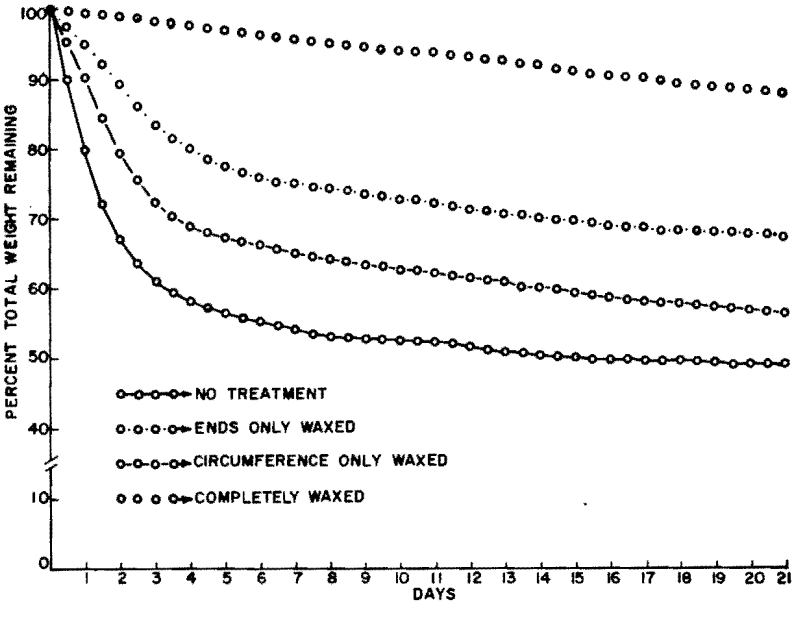
NO TREATMENT
ENDS ONLY WAXED
CIRCUMFERENCE ONLY WAXED
COMPLETELY WAXED
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21
DAYS


PERCENT TOTAL WEIGHT REMAINING
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NO TREATMENT
ENDS ONLY WAXED
CIRCUMFERENCE ONLY WAXED
COMPLETELY WAXED
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21
DAYS

Table 1. Rate of moisture loss by stem and root sections as effected by different treatments

Plant material and section used	Treatment	Per cent of total weight loss[a] 25%	50%	75%
Ulmus americana (stem)	0[b]	.5	1.0	3.0
	EW	2.0	4.0	7.0
	CW	1.5	2.0	6.0
	W	4.0	8.5	14.0
Ulmus pumila (stem)	0	.5	1.5	3.0
	EW	3.0	7.5	9.0
	CW	1.0	2.0	5.0
	W	5.0	10.0	15.0
Ulmus americana (root)	0	.5	1.0	2.5
	EW	1.0	2.5	4.5
	CW	1.0	3.0	7.5
	W	4.5	10.5	16.0
Ulmus pumila (root)	0	.5	1.5	3.0
	EW	1.5	3.0	7.0
	CW	1.5	3.0	7.0
	W	3.5	8.5	14.5

[a]Using final weight loss as 100 per cent, time given in days.

[b]Sections receiving: 0, no treatment
EW, ends only waxed
CW, circumference only waxed
W, completely waxed

was less than that found for sections in which the ends were exposed. This emphasizes the effectiveness and value of the natural protection offered by the epidermis and cuticle. The loss of moisture from the completely waxed segments was uniform throughout the course of the experiment. Both of the curves (Figures 1 and 2), demonstrate the value of waxing

Table 2. Moisture loss comparison of *Ulmus americana* and *Ulmus pumila* as influenced by treatment

Plant material, treatment received, and section used		Per cent total weight remaining[a]	Moisture loss with value of 100 being given to the amount lost by untreated sections
Ulmus americana: (stem)	O[b]	58.2	100.0
	CW	64.3	90.5
	EW	71.2	81.7
	W	88.1	66.0
Ulmus pumila: (stem)	O	49.3	100.0
	CW	56.5	87.2
	EW	67.7	72.8
	W	88.0	56.0
Ulmus americana: (root)	O	49.6	100.0
	CW	57.3	86.6
	EW	62.5	79.4
	W	85.7	57.8
Ulmus pumila: (root)	O	40.0	100.0
	CW	46.7	85.6
	EW	51.3	78.0
	W	83.5	47.9

[a]At conclusion of experiment.

[b]Sections receiving: O, no treatment
CW, circumference only waxed
EW, ends only waxed
W, completely waxed.

when used as an anti-desiccant on the above ground portions of this type of plant material. A statistical comparison between the relationship of moisture loss rates was not made, since interest was primarily concerned with the trends rather than with specific levels.

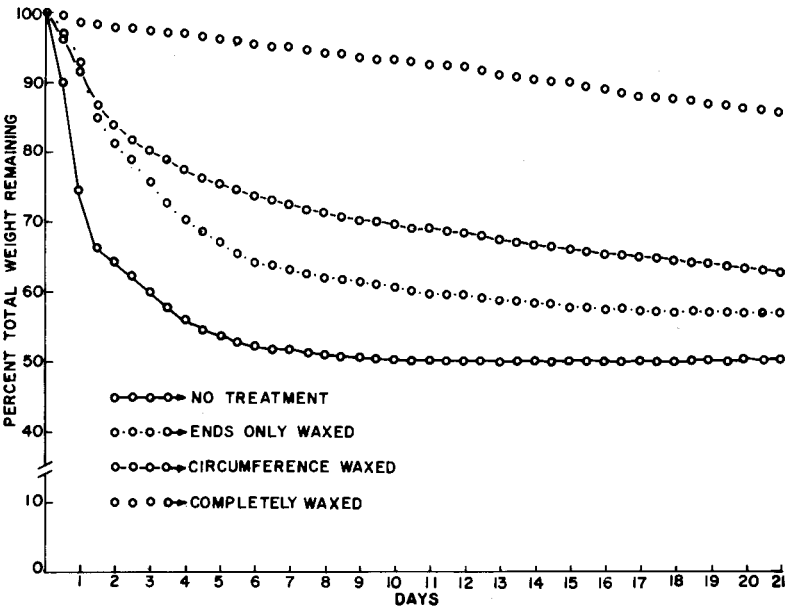
Root treatments

Root sections of both species receiving either no treatment or a complete waxing, responded in the same manner as did the stem sections (Figures 3 and 4). Results for the other two groups of root treatments were unlike those obtained from comparable stem treatments. The group in which the section ends were waxed lost weight rapidly and approached the loss observed for the untreated group. This loss suggests that moisture transfer occurred primarily through the epidermis of the root. This result is not unexpected, since roots do not have external protective tissues or deposits which retard desiccation. Sections in which the circumference was waxed lost moisture more rapidly than did the completely waxed group. However, this loss was less than that observed when wax was applied to the ends of sections. These treatments might have given similar responses had it not been for the slight suberization of the cut ends which occurred a few hours after cutting.

After exposure to room temperature for 21 days, sections of Ulmus pumila weighed less than those of Ulmus americana (Table 2). This was found for both root and stem sections, and may be directly associated with the higher percentage of moisture observed in the tissues of Ulmus pumila.

Figure 3. Rate of moisture loss from root sections of *Ulmus americana*

Figure 4. Rate of moisture loss from root sections of *Ulmus pumila*


PERCENT TOTAL WEIGHT REMAINING
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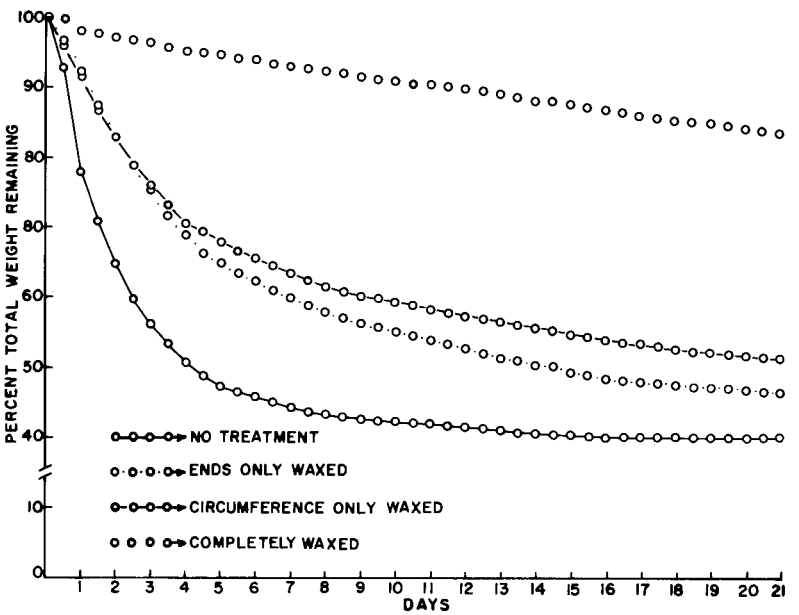
PERCENT TOTAL WEIGHT REMAINING
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DAYS
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CIRCUMFERENCE ONLY WAXED
COMPLETELY WAXED

RESPIRATION EXPERIMENT

Purpose of the Study

The purpose of these experiments was to determine if differences in respiration rates existed between the two species of elms. It was also the goal of these studies to determine differences in respiratory activity as influenced by treatments applied to stem and root portions.

Desiccation studies showed the beneficial effect of waxing on the stem and root portions of both species of Ulmus in reducing moisture loss. It was therefore thought desirable to investigate the effects of waxing and packing on stem sections in terms of respiratory activity, and to correlate these with the effects of different packing materials used on the root portions of the plants.

Materials and Method

These studies were conducted in a series of six experiments involving either stem or root sections of the two species of elms packed in the various treatments. Two of these experiments compared the respiratory activity of either stems or roots packed in sphagnum moss having two levels of moisture. Another experiment compared the respiratory activity of waxed and untreated stem sections of the two species of elms. Root samples from plants which had been

stored bare root were also compared. A composite sample of stem sections receiving the same packing treatment, and a comparison of disbudded stem sections completed the series of experiments.

Special respiration flasks, described by Nagai and Loomis (43), were used throughout the respiration studies. Samples of the gas present within these flasks were drawn at 24 hour intervals, and determinations were made with a Haldane Gas Analyzer. The amount of carbon dioxide and oxygen present in the flasks was computed from the free volume of the flask and percentages of these gases in the sample. Corrections for the 25 ml. samples were made according to the method described by Loomis and Shull (19). Barometric pressures at the time of sampling were obtained through the courtesy of P. J. Waite[1].

Flasks used for all but those experiments conducted in the cooler were placed in an incubator maintained at 86°F. All root and stem sections were approximately 20 gram fresh weight samples and were taken from packages in refrigerated storage. Duplicate samples of waxed stem sections were used to determine the weight of wax per unit of fresh weight.

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[1]P. J. Waite. Des Moines, Iowa. United States Department of Commerce, Weather Bureau. Data pertaining to barometric pressures. Private communication. 1959.

Since the application of wax was performed by the immersion of stems in a large, controlled temperature waxing vat, it was assumed that the application of wax was rather uniform. Samples taken of these sections were equal to the fresh weight of those used in the other respiration studies. The sections were 10 cm. in length, with the exception of one which was cut to bring the final composite sample weight to 20 grams. The number of sections involved in a sample was therefore dependent upon section weight.

In each experiment, one flask was used for a single treatment. Treatments tested in these studies involved all four stem environments and the three root environments provided for each species. Four flasks, with their respective treatments comprised one experiment.

All of the data collected in any one experiment must be interpreted in view of the fact that legitimate comparisons may only be assumed between similar treatments of the two species and the fact that replications of identical material were not made. Therefore, the data in each experiment conducted present evidence, but not proof of the respiration responses of both species of Ulmus as influenced by treatment effects.

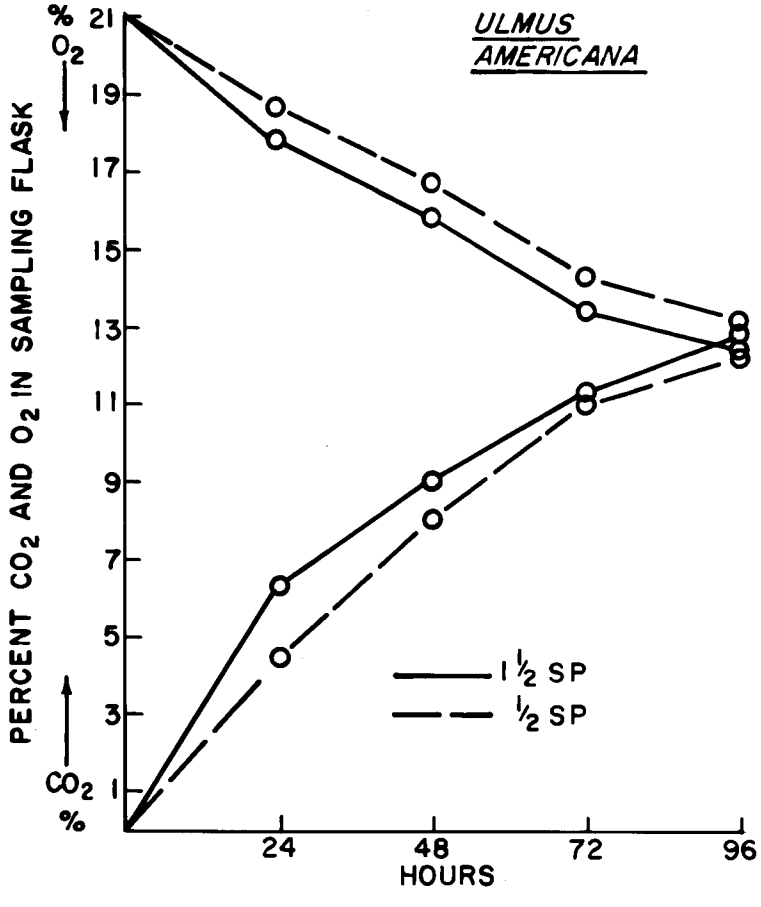
Results and Discussion

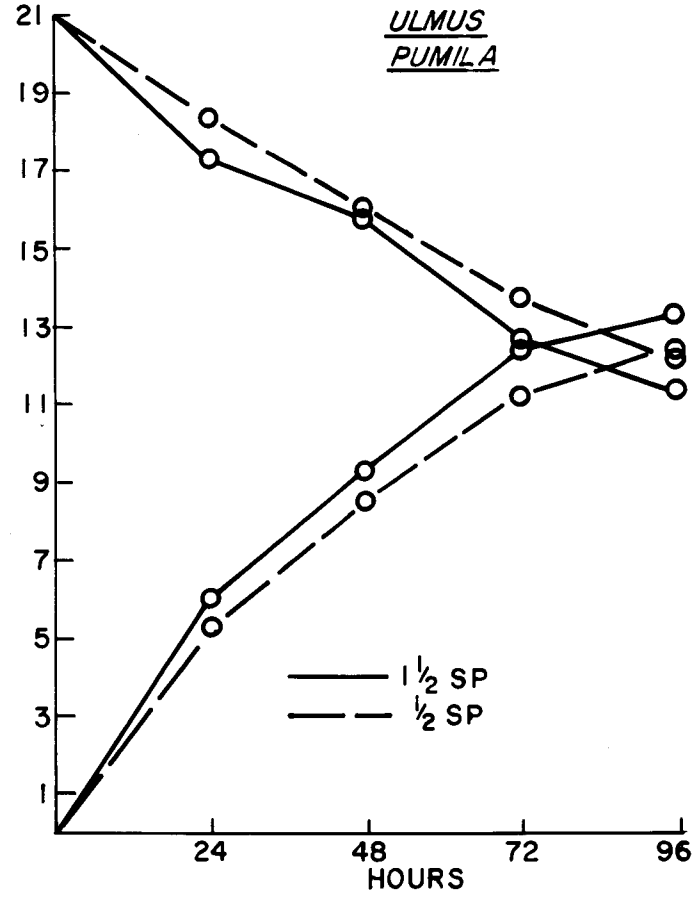
Experiment 1

This experiment compared the respiratory activity of stem sections of Ulmus americana and Ulmus pumila packaged in sphagnum moss containing one-half gallon of water per bushel (½ SP), and one and one-half gallons of water per bushel of moss (1½ SP). The trend of carbon dioxide production and oxygen consumption at 24 hour sampling intervals is shown in Figure 5. The 1½ SP treatment, for both species, maintained a consistently higher CO_2 production and O_2 consumption than the ½ SP treatment. Differences between similar treatments for both species were small. All figures pertaining to the respiration studies show the expected inverse relationship between CO_2 and O_2.

Respiratory quotients, symbolized as R.Q., and the CO_2 production in milliliters of CO_2 per gram dry sample per hour were calculated for each treatment according to the method described by Loomis and Shull (19). From the data, Table 3, it is apparent that both the respiratory quotient and the ml. CO_2 per gram dry weight per hour were also higher in the 1½ SP treatments than the ½ SP treatment for both species. Therefore, according to these data, a slightly higher rate of respiration occurs in stem sections of Ulmus pumila and in the sphagnum stem packs with the greatest moisture con-

Figure 5. Effects of stem pack treatments on respiration


ULMUS AMERICANA
PERCENT CO_2 AND O_2 IN SAMPLING FLASK
% O_2
CO_2 %
21
19
17
15
13
11
9
7
5
3
1
1½ SP
½ SP
24
48
72
96
HOURS


ULMUS PUMILA
21
19
17
15
13
11
9
7
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3
1
1½ SP
½ SP
24
48
72
96
HOURS

Table 3. Comparison of respiratory activity for seedlings of *Ulmus americana* and *Ulmus pumila*

Exp.	Tmt.	Plant species	Gas analysis, Intervals in hours								R.Q.	Ml. CO_2 per gm. dry wt. per hr.
			24		48		72		96			
			CO_2	O_2	CO_2	O_2	CO_2	O_2	CO_2	O_2		
1	1½ SP	U. americana	6.2	17.9	9.0	15.9	11.1	13.3	12.8	12.4	1.20	.19
	1½ SP	U. pumila	6.0	17.3	9.1	15.9	12.2	12.4	13.1	11.3	1.28	.20
	½ SP	U. americana	4.5	18.6	8.0	16.7	11.0	14.1	12.2	13.1	1.18	.18
	½ SP	U. pumila	5.2	18.3	8.5	16.0	11.1	13.7	12.3	12.2	1.18	.20
2	W	U. americana	2.4	17.8	5.6	16.4	6.7	14.4	7.0	13.7	1.05	.11
	W	U. pumila	2.0	17.8	4.6	16.7	7.2	14.4	8.2	13.8	1.07	.12
	0 SP	U. americana	4.8	16.1	8.1	14.9	10.2	12.7	12.6	12.3	1.33	.17
	0 SP	U. pumila	4.3	16.1	7.8	14.1	10.9	12.4	12.6	11.7	1.36	.19
3	1½ RP	U. americana	7.7	16.8	12.1	14.3	13.3	12.3	13.9	11.3	1.58	.26
	1½ RP	U. pumila	8.4	16.4	12.1	13.1	13.7	11.4	14.6	10.9	1.63	.28
	½ RP	U. americana	6.1	17.9	11.5	15.0	12.6	13.2	13.8	11.6	1.51	.25
	½ RP	U. pumila	7.7	17.4	11.6	14.5	12.7	12.3	13.8	11.6	1.59	.28
4	0 RP	U. americana	5.1	18.7	9.3	15.9	11.3	14.5	12.9	12.4	1.33	.22
	0 RP	U. pumila	6.0	18.1	10.2	15.3	11.3	13.1	13.3	11.9	1.38	.24
6	Disbud	U. americana	6.3	15.9	9.3	12.9	12.5	9.9			1.44	.26
	Disbud	U. pumila	8.4	14.8	11.8	11.3	14.3	8.7			1.53	.35
	Disbud	U. americana	8.0	14.5	10.8	12.1	11.7	10.8			1.49	.28
	Disbud	U. pumila	9.0	14.0	11.4	10.9	13.1	9.5			1.55	.33

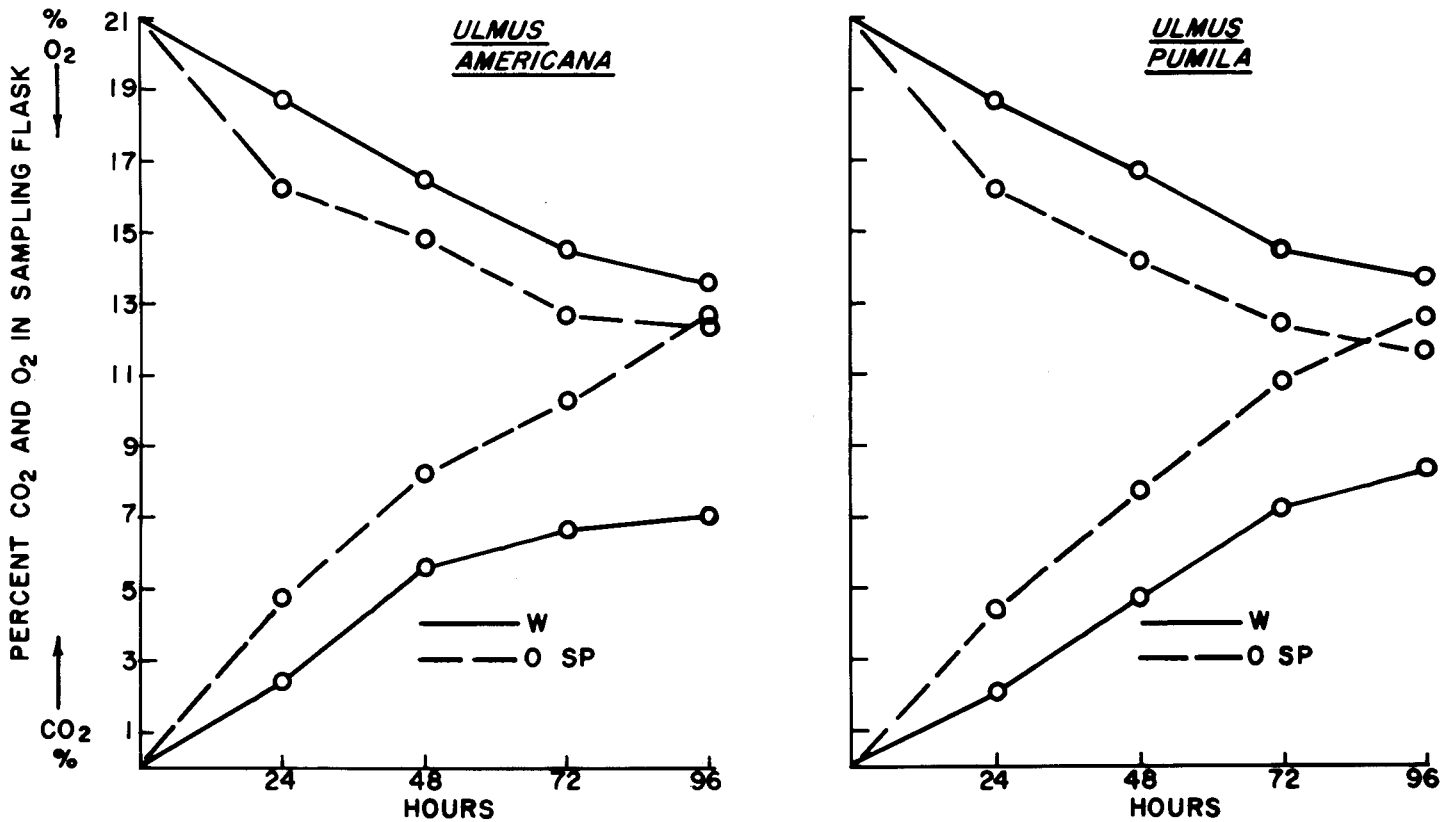
centration. The significance of this rate in comparison to Ulmus americana was not determined, since only one replication was involved.

Experiment 2

In this study, the respiratory activity of stem sections which had been waxed and stored without any stem packaging were compared. The application of wax reduced the amount of respiratory activity for both species. Waxing stem sections reduced the amount of CO_2 produced and O_2 consumed by approximately 20 per cent relative to untreated sections (Figure 6). This is also shown in the ml. CO_2 per gram dry weight per hour determinations for both species as shown in Table 3. It may be concluded therefore, that waxing stem portions not only serves to conserve water within the stem, as demonstrated by the desiccation studies, but also serves as a means of depressing or retarding respiratory activity up to one-fifth the normal rate. The role of waxing is probably that of a physical obstruction to the exchange of gases between the sections and the surrounding atmosphere.

The untreated sections for both species responded quite similarly to the ½ SP and 1½ SP treatments (Figures 5 and 6). The R.Q. and the ml. CO_2 per gram dry weight per hour of Ulmus pumila exceeded the values found for Ulmus americana (Table 3). The amounts of CO_2 produced and O_2 consumed were

Figure 6. Comparison of normal storage and stem waxing treatments on respiration


ULMUS AMERICANA
ULMUS PUMILA
PERCENT CO_2 AND O_2 IN SAMPLING FLASK
% O_2
CO_2 %
21
19
17
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5
3
1
24
48
72
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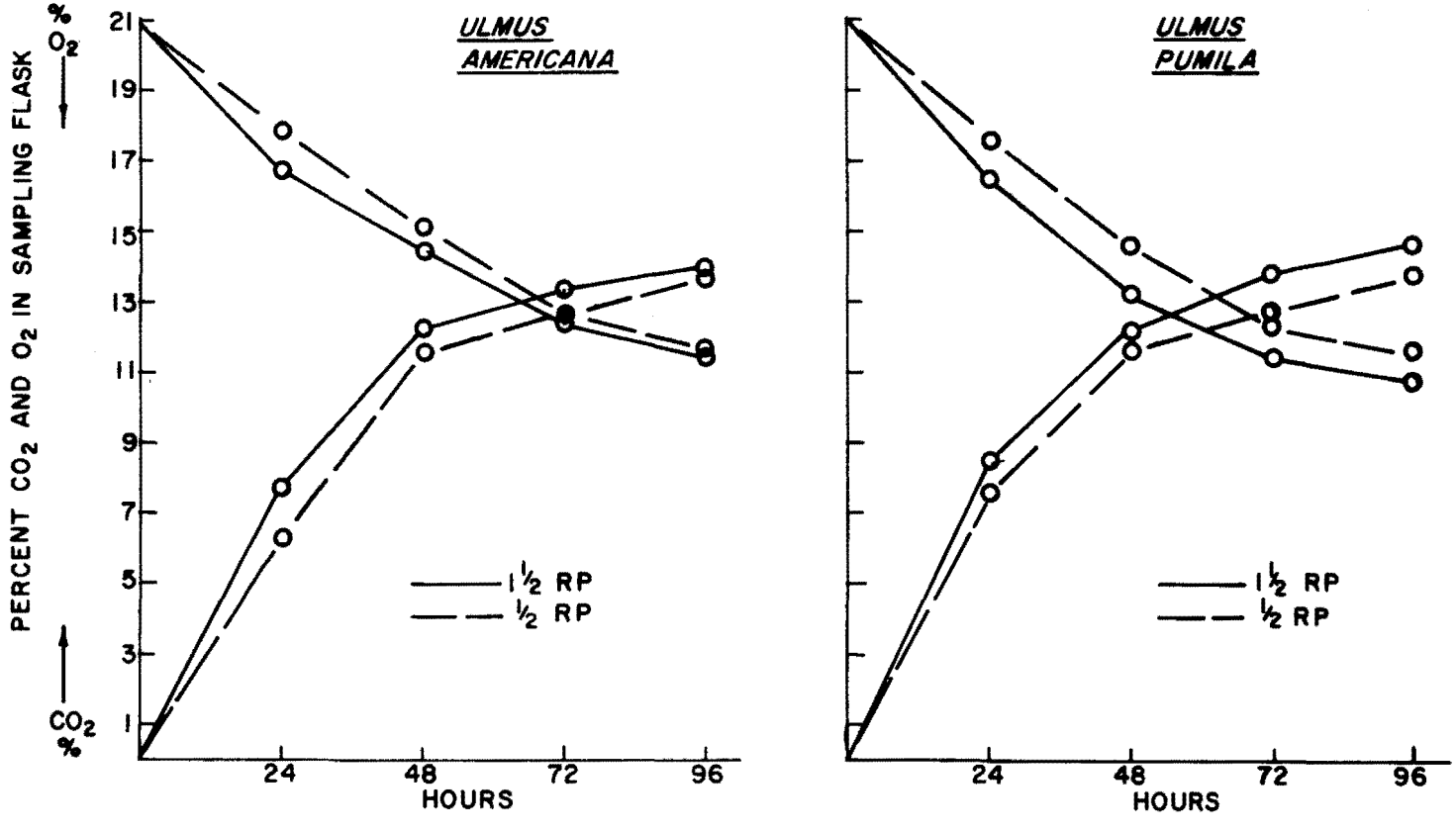
HOURS
W
O SP

not consistently high for sections of Ulmus pumila at each observation period. However, the final results suggest that this species respires at a higher rate than does Ulmus americana.

Experiment 3

In order to compare the respiratory activity of comparable root sections of the two species of elms in the two moisture level packs, a third series of tests was conducted. Data presented in Figure 7, and Table 3 show that respiration rates as measured by CO_2 production, O_2 consumption, and ml. CO_2 per gram dry weight per hour for the root sections are occurring at a higher rate than for stem sections (Figures 5 and 6; Table 3). The data in Figure 7 suggest that sections of the 1⅓ RP treatment for Ulmus pumila were respiring at a slightly higher rate than similar sections of Ulmus americana. The values for the two species in the ⅓ RP treatment were quite similar. However, in Table 3, a wide variation between amounts of CO_2 per gram dry weight per hour was found between the ⅓ RP treatments of the two species. Results of this experiment further support the previous data in which Ulmus pumila consistently maintained a higher respiratory activity than similar sections of Ulmus americana.

Figure 7. Effect of root pack treatments on respiration


ULMUS AMERICANA
ULMUS PUMILA
PERCENT CO_2 AND O_2 IN SAMPLING FLASK
% O_2
CO_2 %
21
19
17
15
13
11
9
7
5
3
1
24
48
72
96
HOURS
1½ RP
½ RP

Experiment 4

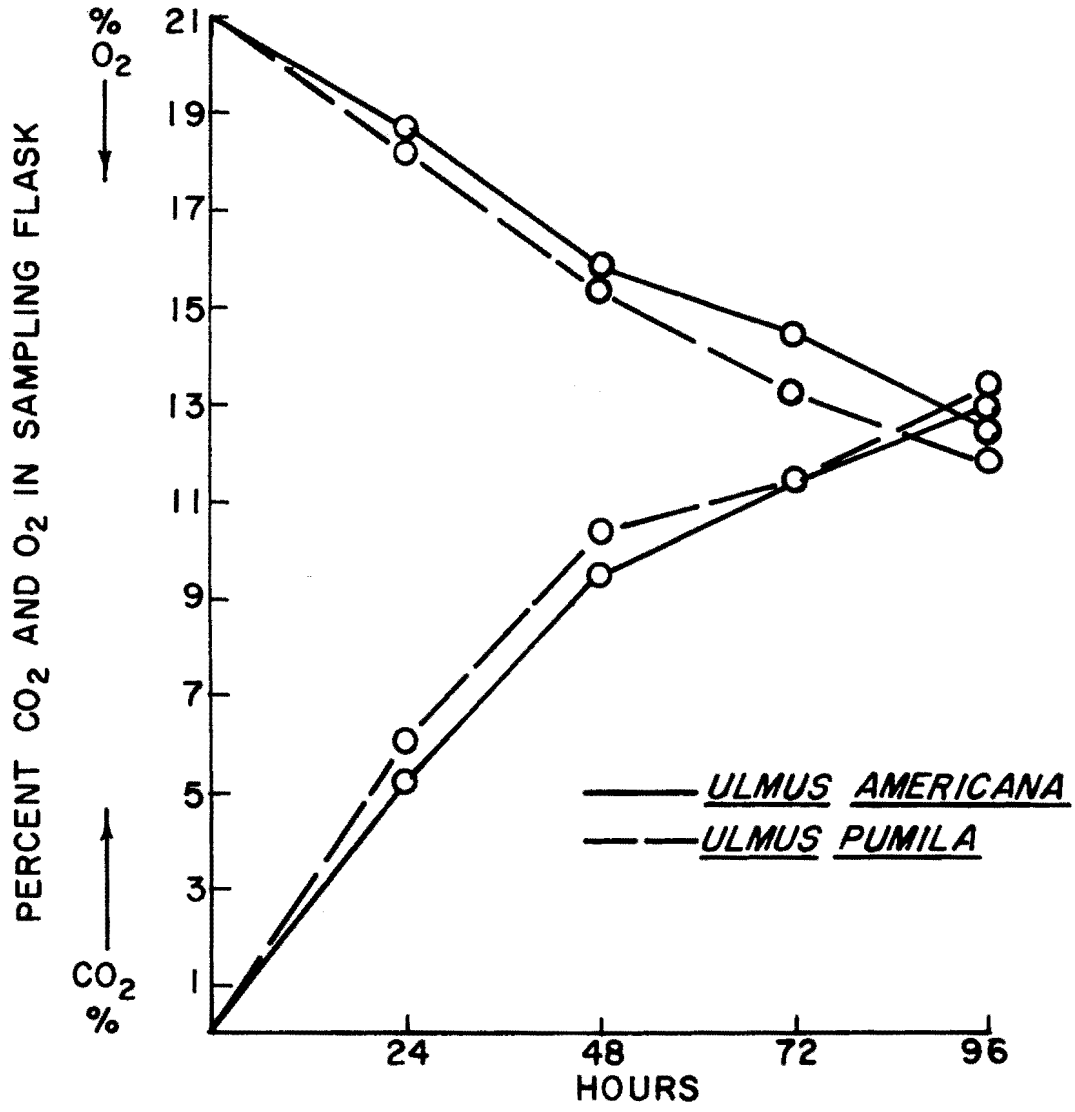
The response of root sections receiving no root packaging treatment, in terms of CO_2 production and O_2 consumption, was quite similar to that obtained from untreated stem sections. There was more variation between root and stem sections packaged in the sphagnum packs. The R.Q. and the ml. CO_2 per gram dry weight per hour for the root sections were considerably higher than those exhibited by the stem portions. Overall results were similar to those obtained in the preceding experiments in that Ulmus americana sections consistently maintained a lower respiratory activity than did similar sections of Ulmus pumila (Figure 8; Table 3).

Experiment 5

Since only one replication was involved in the preceding experiments, and since experimental material was limited, an additional experiment was conducted to determine if respiratory differences actually existed between the two species.

For these determinations, a composite 25 gram sample of stem sections involving the same stem treatments were combined, disregarding the root treatments involved. By having a larger size sample for determinations of the amounts of CO_2 produced and the O_2 consumed, only one determination was considered necessary. This determination was made two days after the beginning of the experiment. The results were

Figure 8. Effects of bare root storage on respiration


PERCENT CO_2 AND O_2 IN SAMPLING FLASK
% O_2
CO_2 %
21
19
17
15
13
11
9
7
5
3
1
24
48
72
96
HOURS
ULMUS AMERICANA
ULMUS PUMILA

quite similar to those obtained earlier. In every instance the CO_2 production and the R.Q. for sections of Ulmus pumila were equal to or exceeded those obtained for comparable sections of Ulmus americana. Similar results were obtained for root sections.

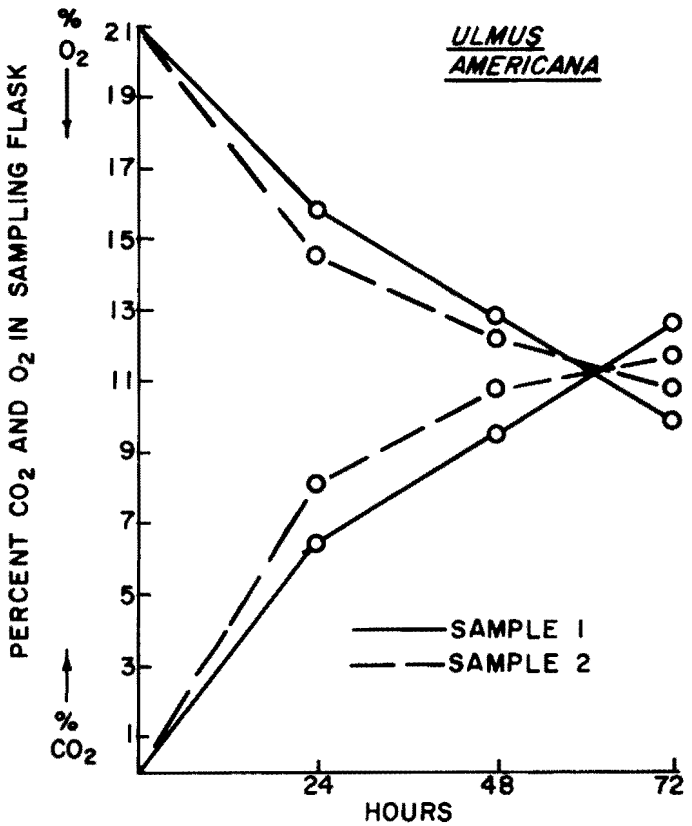
Experiment 6

It was hypothesized that the higher respiration rates of Ulmus pumila might be related to the large number of buds. In an attempt to test this hypothesis, an experiment was conducted using sections of both species from which buds had been removed. Duplicate samples of the two species were then sealed in the respiration flasks, and measurements were recorded over a three day period.

Theoretically, if buds of Ulmus pumila were responsible for the increased respiratory activity, then the removal of these buds would serve to reduce the total production of CO_2 and the amount of O_2 consumed. The effect of wounding, however, caused by bud removal served to mask this relationship. The data obtained are recorded in Figure 9, and Table 3, and are probably an index of the effect of wounding upon the sections.

In order to treat both stem sections similarly, existing buds were removed from duplicate samples for both of the species. The number of wounds was recorded for these stem

Figure 9. Effect of bud removal on the respiration of stem sections


ULMUS AMERICANA
PERCENT CO_2 AND O_2 IN SAMPLING FLASK
% O_2
% CO_2
21
19
17
15
13
11
9
7
5
3
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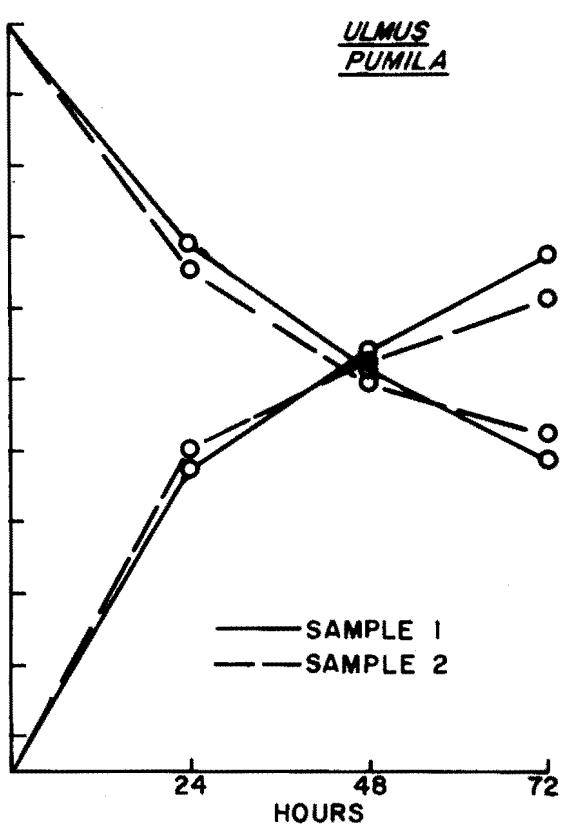
24
48
72
HOURS
SAMPLE 1
SAMPLE 2


ULMUS PUMILA
24
48
72
HOURS
SAMPLE 1
SAMPLE 2

sections. Sections of Ulmus pumila maintained slightly over 44 per cent more wounded area per given unit of stem than did the comparable sections of Ulmus americana. For four inch sections of Ulmus americana, the mean number of buds removed was 4.52, while sections of Ulmus pumila maintained an overall mean of 8.20. In two replications of comparable material, respiration rates measured at regular intervals were found to be greater for Ulmus pumila sections than for the sections of Ulmus americana (Figure 9; Table 3).

The removal of buds may have eliminated or moderated the source of auxin contributing to the initiation or suppression of bud development in either of the species. The exact nature of the specific causes of increased bud break of Ulmus pumila is not known.

All of the data suggest that Ulmus pumila has a higher respiration rate than Ulmus americana. Since the R.Q. used in combination with the CO_2 production in milliliters of CO_2 per gram dry sample per hour gives a fairly complete picture of respiration rates and processes (19), it is suggested that Ulmus pumila exhibits more respiratory activity than does Ulmus americana. One possible cause for the higher respiratory activity could be due to the greater number of buds present upon branches of Ulmus pumila. A greater percentage of these buds develop into sheets. However, this is not the explanation for the increased respiratory activity exhibited by the

root sections of the same species. Another hypothesis is that the increased rates might be due to the difference in moisture content between the two species.

Since the laboratory conditions under which these samples were maintained would not be encountered by the two species of elm in storage, it must be assumed that these responses are in direct relation to those encountered under actual storage conditions.

No data are presented for studies conducted within the refrigerated storage since the very small amounts of CO_2 and O_2 present within the flasks would tend to greatly magnify any results or differences which were encountered.

STORAGE EXPERIMENT

Purpose of the Study

Preliminary investigations had established the characteristics of moisture loss from the root and stem sections for the two species of elms under observation. It was then felt desirable to apply various treatments to these plant parts as an attempt to determine a method of storage that might be satisfactory. The responses of Ulmus americana and Ulmus pumila to root and stem environments were evaluated in terms of bud break, root initial development, changes in moisture content of the plants, the presence of mold, and the field response following the storage period.

Materials and Method

Source, selection, and handling plants prior to packaging

Three hundred one-year old seedlings of Ulmus americana and Ulmus pumila were obtained from Mount Arbor Nurseries, Shenandoah, Iowa, January 23, 1959. These plants were held in common storage until March 15th to allow them to reach equilibrium.

Prior to the application of treatments, plants were sorted into three groups, according to size and length. Seedlings of both species were quite uniform and the majority of plants were placed into the medium category. From this

intermediate size group, 216 of the most uniform seedlings were selected for use in the storage experiment. This selection was based upon size, freedom from broken or damaged roots and stems, and overall general appearance.

The selected plants were then trimmed to a 22 inch height, removing excess and extremely small branches. No attempt was made to maintain the same number of branches per plant. For Ulmus americana seedlings, the number of branches ranged from 2 to 4, with an overall mean of 3.10 branches per plant. The overall mean for the number of branches present on seedlings of Ulmus pumila was 3.90, varying between 2 and 5 branches per plant. Caliber measurements were taken six inches above the collar with an Ilgenfritz Grader. The diameter ranged from 2/16 to 3/16 inches. Each plant was then weighed, labeled, and randomly assigned to a specific treatment. Plants of each species were handled in a similar manner.

Treatments applied to seedlings

Storage treatments were designed to provide three root environments in combination with each of four stem environments for each species. The root treatments involved the use of a packing material containing two different moisture levels as well as a bare root environment. The stem treatments made use of a packing material containing the two quantities of

water utilized in the root packs, a treatment consisting of a wax stem dip, and one untreated series. A description of the treatments employed appears in Table 4.

One lot of packing material was prepared by mixing ½ gallon of water with every bushel of shredded moss. Analysis of this mixture (½ g.p.b.), revealed that the mean moisture content was 68.82 per cent with a range from 61.33 to 70.32 per cent. The same analysis conducted on the 1½ gallon treatment (1½ g.p.b.), showed that the mean moisture percentage was 85.99 per cent, with a range of 81.29 to 89.11 per cent.

After mixing this moss with the designated quantity of water, the medium was sealed in a polyethylene bag to permit the material to reach equilibrium and to ensure that the packing material would maintain the desired water percentage. The same general procedures were observed for both the ½ g.p.b. moss (hereafter designated as ½ SP and ½ RP for the sphagnum stem pack and the sphagnum root pack respectively), and the 1½ g.p.b. moss (hereafter designated as the 1½ SP and 1½ RP for the sphagnum stem pack and the sphagnum root pack respectively), treatments.

Application of storage treatments

Handling of stem portions In both the ½ SP and 1½ SP treatments, approximately 64 cubic inches of sphagnum moss

Table 4. Packaging treatments applied to seedlings of Ulmus americana and Ulmus pumila

Treatment number	Root		Stem	
	Code	Treatment	Code	Treatment
1	½ RP	½ g.p.b.[a] Root pack	W	Waxed stems
2	½ RP	½ g.p.b. Root pack	½ SP	½ g.p.b. Stem pack
3	½ RP	½ g.p.b. Root pack	1½ SP	1½ g.p.b. Stem pack
4	½ RP	½ g.p.b. Root pack	0 SP	Untreated
5	1½ RP	1½ g.p.b. Root pack	W	Waxed stems
6	1½ RP	1½ g.p.b. Root pack	½ SP	½ g.p.b. Stem pack
7	1½ RP	1½ g.p.b. Root pack	1½ SP	1½ g.p.b. Stem pack
8	1½ RP	1½ g.p.b. Root pack	0 SP	Untreated
9	0 RP	Bare-root, no treatment	W	Waxed stems
10	0 RP	Bare-root, no treatment	½ SP	½ g.p.b. Stem pack
11	0 RP	Bare-root, no treatment	1½ SP	1½ g.p.b. Stem pack
12	0 RP	Bare-root, no treatment	0 SP	Untreated

[a]Gallons of water per bushel of shredded sphagnum moss.

containing the particular quantity of moisture was placed around the stem portions in one stem package. The stem wrap was then completed, using the same general packaging procedure employed by nurserymen for root wrapping operations. Following completion of the stem pack, a polyethylene bag was inserted over the unit and tied at the crown.

Treatments which eliminated the packing material were enclosed in a polyethylene bag and tied at the crown of the plant. The stems of seedlings which had received the wax dip were not enclosed in polyethylene although the respective root treatments were bagged. Those seedlings involved in the waxed stem treatments were the only series that did not involve complete polyethylene enclosure. Following stem waxing, plants in this treatment were weighed and the increase in weight recorded as the amount of wax present.

Handling of root portions The same general procedure was employed in packing roots as was used for the packaging of the stems. The packages were tied securely at the crown of the plant and a polyethylene bag was placed over the pack and tied at the crown in order to minimize moisture loss. Bare root treatments were enclosed in a polyethylene bag and tied securely at the crown.

Experimental design and statistical analysis

The experiment was designed so that five replications of each treatment would be planted in the field for observation, with each replication consisting of three plants. In order to be sure that an adequate supply of materials was available for corollary experiments during the course of the storage sequence, an additional replication of all treatments was included.

In order to minimize environmental differences, the three plants selected for a given treatment were packaged in the same bundle. This procedure also reduced the space required by the treatments in the refrigerated storage.

A split-plot variance analysis was used to determine the significance of differences between treatments. The two species of elm were considered to be the whole plot, and stem and root treatments were considered to be the sub-plots. The analysis of variance was employed to determine treatment effects and the "F" test was used as a test of significance (5, 39, and 49). A combined analysis was used to detect overall treatment effects. In order to determine differences in response as related to a particular species, a separate analysis was employed for the seedlings of each individual species as an attempt to increase accuracy. Means of stem and root responses were compared by appropriate Least Significant Difference (L.S.D.), with values computed at the

5 and 1 per cent levels of significance. The overall treatment effects, as influenced by the various treatment combinations, were tested by Duncan's multiple range test (12).

The treatment combinations presented in the tables include only those treatments that were significantly greater or significantly smaller than the seedlings included in the check treatment. Although treatments that may be significantly different from each other appear in these comparisons, no differences between these treatments are shown.

The check treatment was considered to be the treatment combination consisting of the root pack employing the ½ g.p.b. moss (½ RP), in conjunction with a polyethylene bag enclosure without packing for the stem (0 SP or untreated stem series).

Measurements were reduced to the mean per plant for the three plants included in any one replication.

Storage of treatments

The 12 plant treatments applied to seedlings of both species were placed in a walk-in refrigerated storage March 20, 1959. The packages were completely randomized within this storage and placed in three household refrigerators from which the cooling mechanisms had been removed. The relative humidity within these refrigerator hulls was maintained at approximately 100 per cent by means of small fans circulating

air over pans of distilled water. The temperature within the walk-in storage was 33°F (± 2°F). At weekly intervals, plant packages were removed from the hulls, randomized and returned to the refrigerator shells. All determinations that were made on the treatment or sample replications were conducted within the storage. At no time during the storage period were the plants removed from the walk-in refrigerated storage room.

Moisture determinations of packing material

It was desirable to follow the change in moisture content of the various combinations of sphagnum moss used as root and stem treatments. These determinations were made by oven drying all samples of the various moisture content mediums used in packaging to a constant weight in a 100°C oven.

On May 1, 1959, two samples of sphagnum moss from either end of each plant package were removed. One of these two samples was used for a specific moisture determination, while the other portion was placed into a composite sample for all treatments employing the same package environment. Thus, the composite sample for any root package contained four samples for any given plant package, while for any individual stem package environment only three samples were used. Following collection of the final storage data, the same general procedure was employed for similar measurements on packaging

materials. These determinations were made on June 4, 1959.

Available moisture determinations of sphagnum packs

In order to test the available moisture within the sphagnum moss stem and root packs during storage, Bouyoucous moisture blocks were employed. Since these moisture blocks were specifically designed for testing the available soil moisture, it was not known if they could be employed as a reliable index for determining or measuring available moisture of these packing materials.

Bouyoucous gypsum blocks (Model Cel-WWD), were inserted into various packing materials and/or combinations of this material prior to final sealing of the packages. The following treatments involving sphagnum packs were included in this study for both species: 1) ½ RP, 2) ½ SP, 3) 1½ RP, 4) 1½ SP, 5) 1½ RP in combination with the ½ SP, and 6) 1½ SP in combination with the ½ RP.

Available moisture readings of the sphagnum packs involved were obtained as the per cent available moisture by use of the Bouyoucous soil moisture meter (Model BN-1). Weekly determinations were made throughout the course of the storage sequence and were obtained within the refrigerated storage area.

Moisture content of plant sections

Moisture determinations of plant parts were made during the storage sequence by oven drying segments of roots and stems taken from the observation replicates of all treatments. Since preliminary studies showed that seedlings maintained a fairly uniform moisture content, only five observations for each plant part and treatment combination were considered necessary to determine an accurate mean value.

Measurement of sprout growth

Sprouting in storage was recorded as to the number of buds forming sprouts, the linear development of these sprouts, and origin of sprout activity, i.e. from the bottom, middle, or upper one-third region of the plant. All data collected were recorded as the mean value per plant for the three plants included in any one plant package or replication. All measurements, other than number or location of sprouts, were recorded in centimeters. The first measurements of sprout activity in storage were taken on May 1, 1959, at the mid-storage observation period. Final, or late storage determinations were taken at the conclusion of the storage period, on June 4, 1959. The mid-storage measurements were taken in the refrigerated storage room, although the latter determinations were made in the holding room, since the plants were unwrapped prior to the transplanting operation.

Measurement of root activity

Direct measurement of root growth at the termination of the storage experiment was unnecessary since neither species nor treatment produced any large amount of root growth. However, there were very noticeable differences in the number of root initials, their development, and the appearance of the old roots.

Ranking was selected as the method of evaluating root initial activity or development. This method was employed as a rapid method to estimate differences in callusing and root initial development without subjecting the plant materials to prolonged exposure. The procedure of five group ranking was found to be reliable, by Mahlstede and Lana (26), as an estimate of treatment effect. Ranking differences in root appearance and/or root initial development were arbitrarily broken down into the five following categories:

1) old roots dull or showing signs of dehydration
2) no or very few root initials present
3) root initials present in moderate amounts
4) a profusion of root initials
5) measurable lateral root growth.

Presence of mold

Prior to the application of any treatment, all plants were given a protective fungicidal dusting for the control

of storage molds. The fungicide used consisted of a mixture of Thiram, Captan, and Fermate. The effectiveness of the fungicide treatment was evaluated at the conclusion of the storage period, prior to field transplanting. A similar procedure as described for root initial evaluation was employed to record differences in mold activity. The infection or presence of mold was ranked according to the following five criteria:

1) complete freedom from mold
2) trace of mold on either stem or root portions
3) moderate mold infestation on either stem or root portions
4) traces of mold on both stem and root portions
5) moderate mold infection on both stem and root portions

Plant weight prior to and following storage

Each plant was weighed prior to the application of a storage treatment but following the application of the fungicide. Following the storage period, seedlings were then re-weighed to ascertain moisture shifts which might have taken place during the holding or storage sequence. This re-weighing of seedlings was performed immediately after their removal from their respective packages at the conclusion of the storage period.

Results and Discussion

Moisture determinations of packing material

The mean values for the five individual treatment determinations, as well as for the composite samples are presented in Table 5. Since results for the two sampling

Table 5. Moisture content of packaging mediums following storage[a]

Treatment No.	Root	Stem	Moisture percentage Ulmus americana Root[b]	Ulmus americana Stem[b]	Ulmus pumila Root[b]	Ulmus pumila Stem[b]
1	½ RP	W	67.77		69.93	
2	½ RP	½ SP	68.80	65.37	66.21	64.42
3	½ RP	1½ SP	65.21	85.22	63.29	86.92
4	½ RP	0 SP	63.31		67.12	
5	1½ RP	W	84.92		84.31	
6	1½ RP	½ SP	85.33	68.81	83.13	62.98
7	1½ RP	1½ SP	86.22	83.99	88.77	85.26
8	1½ RP	0 SP	88.61		85.62	
9	0 RP	W				
10	0 RP	½ SP		67.81		67.76
11	0 RP	1½ SP		86.93		85.53
12	0 RP	0 SP				
Composite samples[c]						
1,2,3,4		½ RP	68.32		66.66	
5,6,7,8		1½ RP	85.66		84.93	
2,6,10		½ SP		67.91		68.22
3,7,11		1½ SP		84.36		86.11

[a]June 4, 1959.

[b]Mean value of 5 plant packages.

[c]Mean value of 20 plant packages for Root Packs, mean value of 15 plant packages for Stem Packs.

periods were quite similar, only the data from the final determination period are presented. Original moisture percentage determinations of the sphagnum pack consisting of the ½ g.p.b. moss revealed that the mean moisture percentage was 68.82 per cent, with a range from 61.33 to 70.32 per cent. For the sphagnum pack consisting of the 1½ g.p.b. moss, the mean moisture percentage was 85.99 per cent with a range from 81.29 to 89.11 per cent. All of the final determinations were included in both the original and mid-storage range of variation. Since the composite samples were quite similar to the original determinations, no statistical analysis of the data was made.

The results obtained were essentially those that one would expect under these packaging and storage conditions. The sealed packages, in addition to the maintenance of a high relative humidity in the micro-climate of the package, did not undergo any appreciable change in moisture content over the course of the experiment.

Available moisture determinations of sphagnum packs

Although Bouyoucous moisture blocks are useful in determining the available moisture in soil, they did not provide an accurate means for determining available moisture in the sphagnum packs. Minor weekly variations in moisture readings can be expected if the moisture blocks are not in

direct contact with the packing material. Anticipating this, the blocks were completely covered with the sphagnum moss before final sealing of the package. Since values exceeding the range of the moisture meter were obtained, and because the moisture shifts did not follow a logical trend, this means of determining available moisture within the sphagnum packs was not considered to be a reliable index.

Moisture content of plant sections

The moisture content of stem and root sections was determined during two stages of the storage period in order to ascertain the effect of the different packaging environments on the moisture content of the particular plant part. The moisture content of the seedlings at early storage was considered to be the same as that obtained in the desiccation experiment. The mean moisture per cent of root sections for Ulmus americana was 54.34 per cent (52.11 to 57.36 per cent), and 62.62 per cent (58.15 to 66.26 per cent), for sections of Ulmus pumila. Stem sections of Ulmus americana maintained an average moisture content of 46.33 per cent (43.45 to 49.43 per cent), while similar sections of Ulmus pumila were observed to have an average value of 51.45 per cent (47.51 to 54.54 per cent).

Stem determinations Higher moisture percentages were generally maintained in all treatments involving the use of wax. All values, however, were quite similar to those obtained in the initial determinations. Even though these values fell within the normal range of variation, they were consistently higher than other observations. This would indicate that the use of wax results in the maintenance of a higher moisture content than do the other treatments that were used (Table 6). Only the moisture content of the bare root treatment without stem protection fell below the normal range of variation. Intermediate values, between those for waxed stems and stems receiving no treatment, were received for stems stored in the sphagnum packs.

Root determinations Root samples taken from plants packaged in the 1½ RP treatment were generally higher in moisture content than the comparable stem sample. This could partially be due to greater amounts of surface moisture which adhered to the periphery of the sections, and not necessarily due to differences in the internal water content of the roots. The ½ RP treatment was intermediate between bare root storage and those roots packaged with the 1½ g.p.b. moss (Table 6).

The mean values for all plant parts involving the same root and/or stem environment are presented in Table 7. The amount of moisture in any one particular plant part does not vary greatly over the storage period. In only one instance

Table 6. Moisture content of Ulmus seedlings at different storage intervals

Treatment No.	Root	Stem	Ulmus americana				Ulmus pumila			
			Root sections[a]		Stem sections[a]		Root sections[a]		Stem sections[a]	
			5/1[b]	6/4[c]	5/1[b]	6/4[c]	5/1[b]	6/4[c]	5/1[b]	6/4[c]
1	½ RP	W	56.33	53.98	48.33	48.01	63.99	62.81	50.42	52.34
2	½ RP	½ SP	53.12	52.32	46.34	45.93	62.41	61.13	50.02	47.93
3	½ RP	1½ SP	54.45	53.23	47.55	47.21	61.48	62.38	49.98	48.88
4	½ RP	0 SP	55.36	53.31	43.99	43.48	58.98	59.82	47.98	47.82
5	1½ RP	W	54.21	55.13	48.11	48.34	64.98	63.21	53.13	52.79
6	1½ RP	½ SP	56.09	54.32	45.88	46.72	63.92	63.19	52.78	51.72
7	1½ RP	1½ SP	55.73	54.81	47.30	47.13	63.33	64.22	52.92	49.23
8	1½ RP	0 SP	55.12	53.41	46.31	45.98	62.21	61.62	49.93	47.82
9	0 RP	W	53.39	53.01	48.78	48.83	60.34	60.93	52.73	51.03
10	0 RP	½ SP	53.38	51.36	46.38	45.01	58.43	58.14	49.23	48.11
11	0 RP	1½ SP	52.91	52.99	46.94	45.88	59.31	59.42	48.21	49.49
12	0 RP	0 SP	52.33	50.49	43.61	41.91	58.09	56.93	46.98	47.42

[a]Mean value of 5 sections per treatment.

[b]May 1, 1959; Mid-storage.

[c]June 4, 1959; Late storage.

Table 7. Composite moisture determinations for all plant sections having the same stem and/or root packaging environment

Packaging environment Treatment numbers	Root[a]	Stem[b]	Ulmus americana				Ulmus pumila			
			Root sections		Stem sections		Root sections		Stem sections	
			5/1[c]	6/4[d]	5/1	6/4	5/1	6/4	5/1	6/4
1,2,3,4	½	RP	54.81	53.21			61.72	61.54		
5,6,7,8	1½	RP	55.29	54.42			63.61	63.06		
9,10,11,12	0	RP	53.00	51.96			59.04	58.86		
Mean			54.37	53.20			61.46	61.15		
Original			54.37	54.37			62.62	62.62		
1,5,9		W			48.40	48.39			52.09	52.05
2,6,10		½			46.20	45.89			50.68	49.25
3,7,11		1½	SP		47.26	46.74			50.37	49.20
4,8,12		0	SP		44.57	43.79			48.30	47.68
Mean					46.61	46.20			50.36	49.55
Original					46.33	46.33			51.45	51.45

[a]Mean value of 20 sections.

[b]Mean value of 15 sections.

[c]Mid-storage observation period.

[d]Late storage observation period.

did the moisture content of any root or stem section fall below the initial range of variation. This value was .15 per cent lower than the original range and cannot be considered different (Table 7).

Original number of branches

American elm seedlings averaged 3.10 branches per plant in comparison to 3.90 branches per plant for seedlings of the Siberian elm. Analyzing original branch data for all of the experimental seedlings for any one species showed that branch numbers were not different between experimental units. When original branch numbers were compared, Ulmus pumila seedlings had significantly more branches than Ulmus americana (Table 8). Bud break and sprout growth data must therefore be interpreted with regard to the greater branch number and buds per unit of stem length for seedlings of Ulmus pumila.

Measurement of sprout growth

Number and origin of sprouts, mid-storage The number of sprouts produced by the seedlings involved in these storage treatments appears in Tables 9 and 10. Only buds which had broken dormancy were counted as sprouts. Total bud break for all treatments showed that Ulmus pumila had approximately 31 per cent more breaks than did the seedlings of Ulmus americana. Considering the fact that seedlings of

Table 8. Original branch numbers found on elm seedlings

No.	Treatment Root	Treatment Stem	Ulmus americana Total	Ulmus americana Mean[a]	Ulmus pumila Total	Ulmus pumila Mean[b]
1	½ RP	W	14.7	2.94	19.6	3.92
2	½ RP	½ SP	16.0	3.20	19.2	3.84
3	½ RP	1½ SP	16.0	3.20	19.9	3.98
4	½ RP	0 SP	15.0	3.00	17.3	3.46
5	1½ RP	W	15.7	3.14	18.2	3.64
6	1½ RP	½ SP	15.3	3.06	19.9	3.98
7	1½ RP	1½ SP	15.5	3.10	19.6	3.92
8	1½ RP	0 SP	14.7	2.94	19.6	3.92
9	0 RP	W	15.7	3.14	18.9	3.78
10	0 RP	½ SP	15.0	3.00	19.6	3.92
11	0 RP	1½ SP	15.7	3.14	19.6	3.92
12	0 RP	0 SP	16.0	3.20	19.9	3.98

[a]Mean value per plant; standard error of mean using generalized error, ± .15.

[b]Mean value per plant; standard error of mean using generalized error, ± .21.

the Siberian elm have approximately twice the number of buds (Table 59), and a greater number of branches (Table 8), than the American elm, it is apparent that the greater number of sprouts does not necessarily imply that seedlings of Ulmus pumila are breaking dormancy at a more rapid rate. For seedlings of both species, the most desirable root treatment environment in so far as suppression of bud break was concerned, consisted of bare root storage (Tables 9, 10, and 11). This environment had significantly fewer buds breaking dormancy than the root treatments involving the two different sphagnum packs (Table 11). From the data compiled there is

Table 9. Number of sprouts observed at mid-storage on seedlings of Ulmus americana

Treatment No.	Root	Stem	Total	Mean[a]	Comparison to check
1	½ RP	W	1.33	.27 ± .63	S[b]
2	½ RP	½ SP	19.67	3.93 ± .49	
3	½ RP	1½ SP	15.67	3.13 ± .49	
4	½ RP	0 SP	23.33	4.67 ± .49	Check
5	1½ RP	W	2.34	.47 ± .55	S
6	1½ RP	½ SP	20.33	4.06 ± .49	
7	1½ RP	1½ SP	16.00	3.20 ± .49	
8	1½ RP	0 SP	22.34	4.47 ± .49	
9	0 RP	W	.00	.00 ± .00	S
10	0 RP	½ SP	10.00	2.00 ± .49	S
11	0 RP	1½ SP	12.00	2.40 ± .00	S
12	0 RP	0 SP	.00	.00 ± .00	S

Analysis of Variance

Source of variation	Degrees of freedom	Mean square	F
Total	59	3.9862	
Treatments	11	16.2278	13.5752**
Root	2	24.7710	20.7219**
Stem	3	30.9944	25.9280**
Interaction	6	5.9967	5.0164**
Replications	4	1.0212	.8542
Error	44	1.1954	

[a]Mean value per plant; standard error of mean using generalized error.

[b]S - significantly smaller at 1 per cent level than check.

**Significant at 1 per cent level.

Table 10. Number of sprouts observed at mid-storage on seedlings of Ulmus pumila

No.	Treatment: Root	Treatment: Stem	Total	Mean[a]	Comparison to check
1	½ RP	W	6.00	1.20 ± .64	S[b]
2	½ RP	½ SP	22.67	4.53 ± .58	
3	½ RP	1½ SP	27.67	5.53 ± .58	
4	½ RP	0 SP	19.00	3.80 ± .58	Check
5	1½ RP	W	10.00	2.00 ± .64	
6	1½ RP	½ SP	28.66	5.73 ± .58	
7	1½ RP	1½ SP	32.33	6.47 ± .58	G[c]
8	1½ RP	0 SP	20.00	4.00 ± .58	
9	0 RP	W	1.00	.20 ± 1.29	S
10	0 RP	½ SP	11.67	2.33 ± .58	
11	0 RP	1½ SP	13.34	2.67 ± .58	
12	0 RP	0 SP	17.33	3.47 ± .58	

Analysis of Variance

Source of variation	Degrees of freedom	Mean square	F
Total	59	4.6572	
Treatments	11	18.0944	10.9331**
Root	2	29.4953	17.8219**
Stem	3	40.0988	24.7661**
Interaction	6	3.2920	1.9891
Replications	4	.4792	.2895
Error	44	1.6550	

[a]Mean value per plant; standard error of mean using generalized error.

[b]S - significantly smaller at 1 per cent level than check.

[c]G - significantly greater at 1 per cent level than check.

**Significant at 1 per cent level.

Table 11. Number of sprouts at mid-storage, test of least significant differences

Root treatment means				Stem treatment means			
Ulmus americana		Ulmus pumila		Ulmus americana		Ulmus pumila	
1½ RP	3.05	1½ RP	4.45	½ SP	3.33	1½ SP	4.88
½ RP	3.00	½ RP	3.76	0 SP	3.04	½ SP	4.20
0 RP	1.10	0 RP	2.16	1½ SP	2.91	0 SP	3.75
				W	.24	W	1.13
L.S.D.		L.S.D.		L.S.D.		L.S.D.	
.05,	.66	.05,	.81	.05,	.80	.05,	.94
.01,	.89	.01,	1.09	.01,	1.07	.01,	1.26

no reason to believe that the two environments provided by the two moisture level packs are any different in relation to bud break.

Stem waxing resulted in the least amount of sprouting. This was observed to be the case with seedlings of both species. No differences in response were attributed to the two sphagnum packs (Table 11).

The most desirable treatment combination, in so far as the suppression of bud break was concerned, consisted of the bare root storage of roots in combination with stem waxing. Bare root seedlings of Ulmus americana that were not waxed or packed in moss were also completely dormant.

When both stem and root treatments were considered, American elm seedlings in the check treatment had significantly more breaks than six of the other combinations (Table 9). All of these treatments either involved waxing of stems or bare root storage. Similar information recorded for seedlings

of Ulmus pumila showed that the treatment combinations involving stem waxing and the ½ RP treatment or bare root storage had significantly less sprout development than the check. No treatment combination was observed to have significantly more sprouts than the check (Table 10). In general, bud break was limited to the upper two-thirds of the main stem and lateral branches.

Total linear growth, mid-storage Analysis of combined data showed that no differences existed between the two species in linear growth of the developing sprouts. This occurred even though a similar analysis indicated that seedlings of Ulmus pumila had a greater number of buds breaking dormancy than seedlings of Ulmus americana. Analysis of data for each individual species revealed differential treatment response. These variations were attributed to stem and root environmental effects (Tables 12 and 13).

Root treatment data for seedlings of Ulmus americana indicated that the two environments forcing the greatest number of sprouts were also those which had the greatest linear growth. Although both of the sphagnum packs were significantly different when compared to the bare root environment, it was apparent that the responses derived from the ½ RP treatment and the 1½ RP treatment were not alike. The root pack consisting of the 1½ g.p.b. moss was significantly different from the ½ g.p.b. moss in that the former treatment

Table 12. Total linear development of sprouts at mid-storage on seedlings of Ulmus americana

No.	Treatment: Root		Treatment: Stem		Total	Mean[a]	Comparison to check
1	½	RP	W		1.00	.20 ± .85	S[b]
2	½	RP	½	SP	17.66	3.53 ± .66	S
3	½	RP	1½	SP	27.47	5.49 ± .66	S
4	½	RP	0	SP	50.00	10.00 ± .66	Check
5	1½	RP	W		10.00	2.00 ± .73	S
6	1½	RP	½	SP	20.01	4.00 ± .66	S
7	1½	RP	1½	SP	19.16	3.83 ± .66	S
8	1½	RP	0	SP	67.64	13.53 ± .66	G[c]
9	0	RP	W		.00	.00 ± .00	S
10	0	RP	½	SP	14.36	2.87 ± .66	S
11	0	RP	1½	SP	26.83	5.37 ± .66	S
12	0	RP	0	SP	.00	.00 ± .00	S

Analysis of Variance

Source of variation	Degrees of freedom	Mean square	F
Total	59	17.2343	
Treatments	11	82.8067	37.9221**
Root	2	76.3704	34.9745**
Stem	3	131.5144	60.2282**
Interaction	6	60.5984	27.7516**
Replications	4	2.4678	1.1301
Error	44	2.1836	

[a]Mean value per plant; standard error of mean using generalized error; measurements in centimeters.

[b]S - significantly smaller at 1 per cent level than check.

[c]G - significantly greater at 1 per cent level than check.

**Significant at 1 per cent level.

Table 13. Total linear development of sprouts at mid-storage on seedlings of Ulmus pumila

Treatment No.	Root	Stem	Total	Mean[a]	Comparison to check
1	½ RP	W	3.41	.68 ± .71	S[b]
2	½ RP	½ SP	18.07	3.61 ± .64	S
3	½ RP	1½ SP	15.55	3.11 ± .64	S
4	½ RP	0 SP	44.92	8.98 ± .64	Check
5	1½ RP	W	15.68	3.14 ± .64	S
6	1½ RP	½ SP	12.11	2.42 ± .64	S
7	1½ RP	1½ SP	19.93	3.99 ± .64	S
8	1½ RP	0 SP	50.47	10.09 ± .64	
9	0 RP	W	.50	.10 ± 1.43	S
10	0 RP	½ SP	15.01	3.00 ± .64	S
11	0 RP	1½ SP	10.52	2.10 ± .64	S
12	0 RP	0 SP	12.36	2.47 ± .64	S

Analysis of Variance

Source of variation	Degrees of freedom	Mean square	F
Total	59	9.9044	
Treatments	11	44.4378	21.8743**
Root	2	47.6985	23.4794**
Stem	3	93.6250	46.0866**
Interaction	6	18.7199	9.2148**
Replications	4	1.5397	.7597
Error	44	2.0315	

[a]Mean value per plant; standard error of mean using generalized error; measurements in centimeters.

[b]S - significantly smaller at 1 per cent level than check.

**Significant at 1 per cent level.

resulted in more total sprout growth (Table 14). Data on the root treatments applied to seedlings of Ulmus pumila showed that the moss packs resulted in the greatest amount of growth. There was no evidence to suggest that the response derived from the two moisture level packs was different.

Data on stem treatments applied to Ulmus americana seedlings showed that waxing generally produced less sprout growth than the other treatments. The 1½ SP treatment was generally more conducive to growth than the ½ SP treatment. The same relationship of waxed and untreated stem treatments to sprout growth existed for seedlings of Ulmus pumila. Only relatively small differences existed between the sprout growth forced on seedlings in the two sphagnum stem packs.

Analyzing the sprout growth response on the basis of both stem and root treatments applied to seedlings of Ulmus americana, treatment 8 (1½ RP, 0 SP), was the only one to exceed the check in total growth (Table 12). Treatments 4 and 8 gave similar growth responses for seedlings of Ulmus pumila. This response was significantly greater than that produced by plants in the remaining treatments (Table 13).

Number of sprouts, late storage Although differences in bud break were more pronounced after 11 weeks of storage, the trends observed at the mid-storage observation period persisted. For example, the total number of sprouts for all replications and all treatment combinations was 323.67 for

Table 14. Total linear development of sprouts at mid-storage, test of least significant differences

Root treatment means				Stem treatment means			
Ulmus americana		Ulmus pumila		Ulmus americana		Ulmus pumila	
1½ RP	5.84	1½ RP	4.90	0 SP	7.84	0 SP	7.18
½ RP	4.80	½ RP	4.09	1½ SP	4.89	1½ SP	3.06
0 RP	2.05	0 RP	1.91	½ SP	3.46	½ SP	3.01
				W	.73	W	1.30
L.S.D.		L.S.D.		L.S.D.		L.S.D.	
.05, .94		.05, .90		.05, 1.08		.05, 1.04	
.01, 1.25		.01, 1.21		.01, 1.45		.01, 1.40	

seedlings of Ulmus americana and 573.01 for seedlings of Ulmus pumila. However, pronounced differences existed between the various treatment combinations and the species involved.

A comparison of the total number of buds breaking dormancy at the conclusion of the storage period is presented in Table 15. These figures represent the total number of sprouts present as influenced by the three root and four stem environments. When the total number of buds breaking dormancy in the twelve treatment combinations were compiled, 43.51 per cent more sprouts were formed on seedlings of the Siberian elm. There was little variation between Ulmus americana seedlings packaged in the ½ and 1½ g.p.b. moss root packs as related to differences in root treatment effects.

Seedlings of Ulmus pumila produced 34 per cent more new sprouts than Ulmus americana in similar sphagnum root packs. The number of buds produced by Siberian elm seedlings in the

Table 15. Bud break at late storage as influenced by packaging environment

Treatment	*Ulmus pumila*	*Ulmus americana*	Difference in per cent
Root			
½ RP	208.66[a]	136.00[a]	34.82[b]
1½ RP	194.02	128.00	34.03
0 RP	170.33	59.67	67.97
Stem			
W	71.01	36.67	48.36
½ SP	179.00	98.34	45.07
1½ SP	201.32	97.99	51.33
0 SP	121.68	90.67	25.48

[a]Total number of sprouts for all replications receiving the same packaging environment.

[b]Comparison of larger to smaller.

bare root environment was 65 per cent more than for the comparable treatment applied to seedlings of *Ulmus americana*. This represented the greatest difference that existed between species as a result of root treatment.

Considering only similar stem treatments, those receiving no treatment showed the least variation between species. Untreated stem portions of *Ulmus pumila* were observed to have 25 per cent more buds breaking dormancy than the comparable treatment applied to seedlings of *Ulmus americana*. For any one of the remaining three stem treatments, there was 50 per cent more sprout development on *Ulmus pumila* seedlings. Data on sprout number for each species, together with the analysis of variance, are presented in Tables 16 and 17.

Table 16. Number of sprouts observed at late storage on seedlings of *Ulmus americana*

Treatment No.	Root	Stem	Total	Mean[a]	Comparison to check
1	½ RP	W	17.67	3.53 ± .75	S[b]
2	½ RP	½ SP	38.00	7.60 ± .75	
3	½ RP	1½ SP	37.66	7.53 ± .75	
4	½ RP	0 SP	42.67	8.53 ± .75	Check
5	1½ RP	W	19.00	3.80 ± .75	S
6	1½ RP	½ SP	33.33	6.67 ± .75	
7	1½ RP	1½ SP	27.67	5.53 ± .75	S
8	1½ RP	0 SP	48.00	9.60 ± .75	
9	0 RP	W	.00	.00 ± .00	S
10	0 RP	½ SP	27.01	5.40 ± .75	S
11	0 RP	1½ SP	32.66	6.53 ± .75	
12	0 RP	0 SP	.00	.00 ± .00	S

Analysis of Variance

Source of variation	Degrees of freedom	Mean square	F
Total	59	10.9646	
Treatments	11	47.3232	16.7089**
Root	2	87.9938	31.0690**
Stem	3	58.8437	20.7766**
Interaction	6	28.0061	9.8884**
Replications	4	.4350	1.5359
Error	44	2.8322	

[a]Mean value per plant; standard error of mean using generalized error.

[b]S - significantly smaller at 1 per cent level than check.

**Significant at 1 per cent level.

Table 17. Number of sprouts observed at late storage on seedlings of *Ulmus pumila*

No.	Treatment: Root	Treatment: Stem	Total	Mean[a]	Comparison to check
1	½ RP	W	32.99	6.60 ± .76	
2	½ RP	½ SP	65.00	13.00 ± .76	G[b]
3	½ RP	1½ SP	72.66	14.53 ± .76	G
4	½ RP	0 SP	38.01	7.60 ± .76	Check
5	1½ RP	W	36.35	7.27 ± .76	
6	1½ RP	½ SP	53.33	10.67 ± .76	G
7	1½ RP	1½ SP	67.99	13.60 ± .76	G
8	1½ RP	0 SP	36.35	7.27 ± .76	
9	0 RP	W	1.67	.33 ± 1.70	S[c]
10	0 RP	½ SP	60.67	12.13 ± .76	G
11	0 RP	1½ SP	60.67	12.13 ± .76	G
12	0 RP	0 SP	47.32	9.46 ± .76	

Analysis of Variance

Source of variation	Degrees of freedom	Mean square	F
Total	59	17.1583	
Treatments	11	79.7984	27.4778**
Root	2	18.7061	6.4412**
Stem	3	229.6459	79.0764**
Interaction	6	25.2387	8.6907**
Replications	4	1.6941	.5833
Error	44	2.9041	

[a]Mean value per plant; standard error of mean using generalized error.

[b]G - significantly greater at 1 per cent level than check.

[c]S - significantly smaller at 1 per cent level than check.

**Significant at 1 per cent level.

A comparison of the number of sprouts produced, as a result of root treatments applied to seedlings of Ulmus americana, showed that the ½ RP treatment favored the greatest sprout activity. The number of sprouts produced by this treatment was 5.88 per cent greater than for the 1½ RP and 56.13 per cent greater than for the bare root storage environments. With seedlings of Ulmus pumila, the ½ RP treatment resulted in 7.02 per cent greater sprout development than the 1½ RP, and 18.37 per cent greater sprout development than for the bare root storage environments. The general response of Ulmus americana to the various root treatments was similar to that obtained at mid-storage. Analysis of the data would suggest that the most favorable root storage environment, for the suppression of sprouting in storage, would consist of bare root storage. There was a change however, in the response of Ulmus pumila to root treatments between the mid and late storage evaluation periods. Although both of the sphagnum packs resulted in a significantly greater number of sprouts in comparison to the bare root environment, the data suggest that responses between these two packs are not alike. The data also indicate that the ½ RP treatment is more favorable for bud break than is the root pack consisting of the higher moisture concentration (Table 18).

The effects of stem treatments were generally the same

Table 18. Number of sprouts at late storage, test of least significant differences

Root treatment means				Stem treatment means			
Ulmus americana		Ulmus pumila		Ulmus americana		Ulmus pumila	
½ RP	6.80	½ RP	10.43	½ SP	6.55	1½ SP	13.42
1½ RP	6.40	1½ RP	9.70	1½ SP	6.53	½ SP	11.93
0 RP	2.98	0 RP	8.51	0 SP	6.04	0 SP	8.11
				W	2.44	W	4.73
L.S.D.		L.S.D.		L.S.D.		L.S.D.	
.05, 1.07		.05, 1.08		.05, 1.23		.05, 1.25	
.01, 1.43		.01, 1.45		.01, 1.65		.01, 1.67	

as those recorded at mid-storage. Stems which had been waxed maintained significantly less bud development than the stems receiving the other three treatments. No great differences in response were observed between stem treatments not involving the wax stem dip (Table 18). Of these three treatments, the ½ SP treatment resulted in a slightly greater response for seedlings of Ulmus americana while the 1½ SP treatment was found to produce the same effect for Ulmus pumila. The two Ulmus americana treatments which were completely dormant at mid-storage also were dormant at the conclusion of the storage experiment. These treatments included the bare root environment in combination with stem waxing and the untreated stem series.

The treatment combination that was most favorable for continued dormancy was bare root storage in conjunction with stem waxing. From the bud break data gathered at both mid-

and late storage, it is quite apparent that the greatest amount of sprouting occurred when the highest moisture content sphagnum pack was used either as a root and/or stem treatment. Conversely, with lower moisture packs and the elimination of a packing material, seedlings had fewer breaks.

Seedlings of Ulmus americana and Ulmus pumila in the check treatments maintained significantly more sprouts than did the six other treatment combinations (Tables 16 and 17).

Total linear growth, late storage Although seedlings of Ulmus pumila had a greater number of buds which broke dormancy, the total growth of these sprouts was generally less than the amount produced by comparable treatments applied to the root and/or stem portions of Ulmus americana (Table 19).

The total linear sprout growth produced by plants of Ulmus americana for all treatment combinations was 32.94 per cent greater than that produced by the seedlings of Ulmus pumila. Linear growth determinations for the two species appears in Tables 20 and 21. The bare root treatment resulted in the least variation in linear sprout growth as related to the root environments provided for the two species. There was little difference in the effect of moisture levels of the packing materials on linear growth.

For similar stem treatments, Ulmus americana seedlings stored in the sphagnum packs or remaining untreated were

Table 19. Length of sprouts at late storage as influenced by packing environment

Treatment	Ulmus americana	Ulmus pumila	Difference in per cent
Root			
½ RP	254.35[a]	160.95[a]	36.72[b]
1½ RP	235.28	157.69	32.98
0 RP	93.64	72.52	22.56
Stem			
W	48.02	70.51	31.90
½ SP	118.10	67.70	42.66
1½ SP	144.35	64.14	55.57
0 SP	272.84	188.81	30.80

found to maintain 30 to 55 per cent greater linear growth than comparable treatments applied to seedlings of Ulmus pumila. However, for seedlings of Ulmus pumila which received the wax stem dip, the linear development of sprouts was nearly 32 per cent greater than the comparable treatment applied to seedlings of Ulmus americana. While waxing of the stem portions was responsible for the least linear development of sprouts on seedlings of Ulmus americana, the same treatment resulted in the greatest linear growth for seedlings of Ulmus pumila, with the exception of the untreated stem series (Table 22).

Root treatment effects were the same for both species. The environment most conducive to the linear development of sprouts was the ½ RP treatment. Bare root storage resulted in the least amount of linear growth. Although no differences were present between the ½ RP treatment and the 1½ RP treat-

Table 20. Total linear development of sprouts at late storage on seedlings of Ulmus americana

No.	Treatment Root	Stem	Total	Mean[a]	Comparison to check
1	½ RP	W	27.73	5.55 ± 1.70	S[b]
2	½ RP	½ SP	37.75	7.55 ± 1.70	S
3	½ RP	1½ SP	59.15	11.83 ± 1.70	S
4	½ RP	0 SP	129.72	25.94 ± 1.70	Check
5	1½ RP	W	20.29	4.06 ± 1.70	S
6	1½ RP	½ SP	40.62	8.12 ± 1.70	S
7	1½ RP	1½ SP	31.25	6.25 ± 1.70	S
8	1½ RP	0 SP	143.12	28.62 ± 1.70	
9	0 RP	W	.00	.00 ± .00	S
10	0 RP	½ SP	39.69	7.94 ± 1.70	S
11	0 RP	1½ SP	53.95	10.79 ± 1.70	S
12	0 RP	0 SP	.00	.00 ± .00	S

Analysis of Variance

Source of variation	Degrees of freedom	Mean square	F
Total	59	86.8032	
Treatments	11	403.2210	27.9416**
Root	2	385.4438	26.7098**
Stem	3	588.2600	40.7641**
Interaction	6	316.6272	21.9410**
Replications	4	12.7506	.8835
Error	44	14.4308	

[a]Mean value per plant; standard error of mean using generalized error; measurements in centimeters.

[b]S - significantly smaller at 1 per cent level than check.

**Significant at 1 per cent level.

Table 21. Total linear development of sprouts at late storage on seedlings of Ulmus pumila

No.	Treatment Root	Stem	Total	Mean[a]	Comparison to check
1	½ RP	W	39.55	7.91 ± 1.00	S[b]
2	½ RP	½ SP	28.88	5.78 ± 1.00	S
3	½ RP	1½ SP	23.34	4.67 ± 1.00	S
4	½ RP	0 SP	69.18	13.84 ± 1.00	Check
5	1½ RP	W	29.96	5.99 ± 1.00	S
6	1½ RP	½ SP	12.21	2.44 ± 1.00	S
7	1½ RP	1½ SP	24.78	4.96 ± 1.00	S
8	1½ RP	0 SP	90.74	18.15 ± 1.00	g[c]
9	0 RP	W	1.00	.20 ± 2.24	S
10	0 RP	½ SP	26.61	5.32 ± 1.00	S
11	0 RP	1½ SP	16.02	3.20 ± 1.00	S
12	0 RP	0 SP	28.89	5.78 ± 1.00	S

Analysis of Variance

Source of variation	Degrees of freedom	Mean square	F
Total	59	26.6123	
Treatments	11	121.3312	24.2192**
Root	2	125.7035	25.0920**
Stem	3	245.9237	49.0895**
Interaction	6	57.5775	11.4932**
Replications	4	3.7644	.7514
Error	44	5.0097	

[a]Mean value per plant; standard error of mean using generalized error; measurements in centimeters.

[b]S - significantly smaller at 1 per cent level than check.

[c]g - significantly greater at 5 per cent level than check.

**Significant at 1 per cent level.

Table 22. Total linear development of sprouts at late storage, test of least significant differences

Root treatment means				Stem treatment means			
Ulmus americana		Ulmus pumila		Ulmus americana		Ulmus pumila	
½ RP	12.71	½ RP	8.04	0 SP	18.18	0 SP	12.58
1½ RP	11.76	1½ RP	7.88	1½ SP	9.62	W	4.70
0 RP	4.68	0 RP	3.62	½ SP	7.87	½ SP	4.51
				W	3.20	1½ SP	4.27
L.S.D.		L.S.D.		L.S.D.		L.S.D.	
.05, 2.42		.05, 1.42		.05, 2.79		.05, 1.64	
.01, 3.32		.01, 1.90		.01, 3.73		.01, 2.19	

ment, both were found tc be responsible for significantly greater linear growth than seedlings stored bare root (Table 22).

For stem treatment effects on seedlings of Ulmus americana, results obtained were quite similar when compared to those encountered at mid-storage. Waxing of stems resulted in significantly less linear development than any of the other stem treatments employed. Also, stems receiving no treatment were observed to maintain significantly more growth than the stem treatments employing the wax stem dip or the sphagnum packs. No differences were found to exist between the ½ SP treatment and the 1½ SP treatment (Table 22). There were differences in the effect of stem treatments on seedlings of Ulmus pumila. At the final observation period, the untreated stem series had significantly more linear growth than seedlings in the other three stem treat-

ments. No differences were observed between the sphagnum pack or wax stem dip treatments. At the time the first measurements were taken at mid-storage, stem waxing resulted in the least development of sprouts for these three environments. However, at final storage, this treatment was found to be the most conducive for linear growth when compared to the sphagnum stem packs (Table 22).

For seedlings of Ulmus americana, treatments 4 and 8 resulted in significantly more sprout growth than the other treatment combinations. This was not the case for seedlings of Ulmus pumila, since treatment 8 resulted in more growth than treatment 4, the check (Tables 20 and 21).

Average sprout length, late storage The combined analysis of variance revealed that the average length of sprouts produced by the American elm seedlings was significantly greater than for comparable Siberian elm measurements. The total average sprout length for all replications of both species receiving the same packaging environment is presented in Table 23.

After combining the average length of sprouts which developed after the twelve treatment combinations were applied, Ulmus americana seedlings gave measurements that were 32.94 per cent greater than those of Ulmus pumila. Data for average sprout length measurements for the individual species appear in Tables 24 and 25.

Table 23. Total of the average sprout lengths at late storage as influenced by packaging treatment

Treatment	Ulmus americana	Ulmus pumila	Difference in per cent
Root			
½ RP	35.80[a]	19.03[a]	46.84[b]
1½ RP	32.35	19.43	39.94
0 RP	15.59	7.15	54.14
Stem			
W	12.84	10.67	16.90
½ SP	18.62	5.63	69.76
1½ SP	21.54	4.75	77.95
0 SP	30.74	24.56	20.10

[a]Total of the average sprout lengths for all replications receiving the same packaging environment; measurements in centimeters.

[b]Comparison of larger to smaller.

Although the 1½ RP treatment was conducive to greater sprout lengths for seedlings of Ulmus pumila, the ½ RP treatment was found to produce the same effect for seedlings of Ulmus americana (Table 26).

Pronounced differences were found between stem portions receiving the same packaging environment. The widest ranges of variation between species involved the sphagnum stem packs. For seedlings of Ulmus americana, the sphagnum stem packs were found to have sprout lengths that were intermediate between stem waxing and the untreated stem series. However, Ulmus pumila seedlings receiving the sphagnum stem packs were found to have shorter sprouts than either of the other two

Table 24. Average sprout length at late storage for seedlings of *Ulmus americana*

Treatment No.	Root	Stem	Total	Mean[a]	Comparison to check
1	½ RP	W	7.71	1.54 ± .17	S[b]
2	½ RP	½ SP	4.95	.99 ± .17	S
3	½ RP	1½ SP	7.76	1.55 ± .17	S
4	½ RP	0 SP	15.38	3.08 ± .17	Check
5	1½ RP	W	5.13	1.03 ± .17	S
6	1½ RP	½ SP	6.20	1.24 ± .17	S
7	1½ RP	1½ SP	5.66	1.13 ± .17	S
8	1½ RP	0 SP	15.36	3.07 ± .17	
9	0 RP	W	.00	.00 ± .00	S
10	0 RP	½ SP	7.47	1.49 ± .17	S
11	0 RP	1½ SP	8.12	1.62 ± .17	S
12	0 RP	0 SP	.00	.00 ± .00	S

Analysis of Variance

Source of variation	Degrees of freedom	Mean square	F
Total	59	.9665	
Treatments	11	4.5600	31.0838**
Root	2	5.8437	39.8343**
Stem	3	3.7198	25.3565**
Interaction	6	4.5522	31.0306**
Replications	4	.1023	.6873
Error	44	.1467	

[a]Mean value per plant; standard error of mean using generalized error; measurements in centimeters.

[b]S - significantly smaller at 1 per cent level than check.

**Significant at 1 per cent level.

Table 25. Average sprout length at late storage for seedlings of *Ulmus pumila*

No.	Treatment Root	Stem	Total	Mean[a]	Comparison to check
1	½ RP	W	6.13	1.23 ± .10	S[b]
2	½ RP	½ SP	2.23	.45 ± .10	S
3	½ RP	1½ SP	1.59	.32 ± .10	S
4	½ RP	0 SP	9.08	1.82 ± .10	Check
5	1½ RP	W	3.94	.79 ± .10	S
6	1½ RP	½ SP	1.16	.23 ± .10	S
7	1½ RP	1½ SP	1.85	.37 ± .10	S
8	1½ RP	0 SP	12.48	2.50 ± .10	G[c]
9	0 RP	W	.60	.12 ± .23	S
10	0 RP	½ SP	2.24	.45 ± .10	S
11	0 RP	1½ SP	1.31	.26 ± .10	S
12	0 RP	0 SP	3.00	.60 ± .10	S

Analysis of Variance

Source of variation	Degrees of freedom	Mean square	F
Total	59	.5440	
Treatments	11	2.6600	49.3506**
Root	2	2.4341	45.1595**
Stem	3	5.5829	103.5788**
Interaction	6	1.2739	23.6345**
Replications	4	.1153	2.1391
Error	44	.0539	

[a]Mean value per plant; standard error of mean using generalized error; measurements in centimeters.

[b]S - significantly smaller at 1 per cent level than check.

[c]G - significantly greater at 1 per cent level than check.

**Significant at 1 per cent level.

Table 26. Average sprout length at late storage, test of least significant differences

Root treatment means				Stem treatment means			
Ulmus americana		Ulmus pumila		Ulmus americana		Ulmus pumila	
½ RP	1.79	1½ RP	.97	0 SP	2.04	0 SP	1.63
1½ RP	1.61	½ RP	.95	1½ SP	1.43	W	.71
0 RP	.77	0 RP	.35	½ SP	1.24	½ SP	.37
				W	.85	1½ SP	.31
L.S.D.		L.S.D.		L.S.D.		L.S.D.	
.05, .24		.05, .14		.05, .28		.05, .16	
.01, .32		.01, .19		.01, .37		.01, .22	

stem treatments. Differences in the average length of sprouts between the species were 20 per cent or less than for those receiving stem waxing or those remaining untreated. The sprouts formed as a result of the sphagnum stem packs were observed to have differences in excess of 70 per cent.

Stem treatment effects relative to seedlings of Ulmus americana were found to be the same as those responsible for total linear growth. However, quite unlike the response of Ulmus americana seedlings to the different stem environments, seedlings of Ulmus pumila which were waxed produced sprouts that were significantly greater in length than those in the 1½ SP and ½ SP treatments (Table 26).

Overall treatment combination effects were found to be similar to those responsible for total linear growth produced by seedlings of both species (Tables 24 and 25).

Considering all methods of stem packaging, seedlings

remaining untreated were the least desirable because this environment was conducive to profuse sprouting. Since the maintenance of complete dormancy is considered to be the goal of the packaging and storage operation, the bare root environment would appear, at this point, to be the superior root treatment regardless of the species involved. Similarly, the most desirable stem treatment would be that consisting of the wax stem dip.

Sprout development and growth during the storage period, as influenced by the various treatment combinations applied to the two species, appears in Figures 10 through 15.

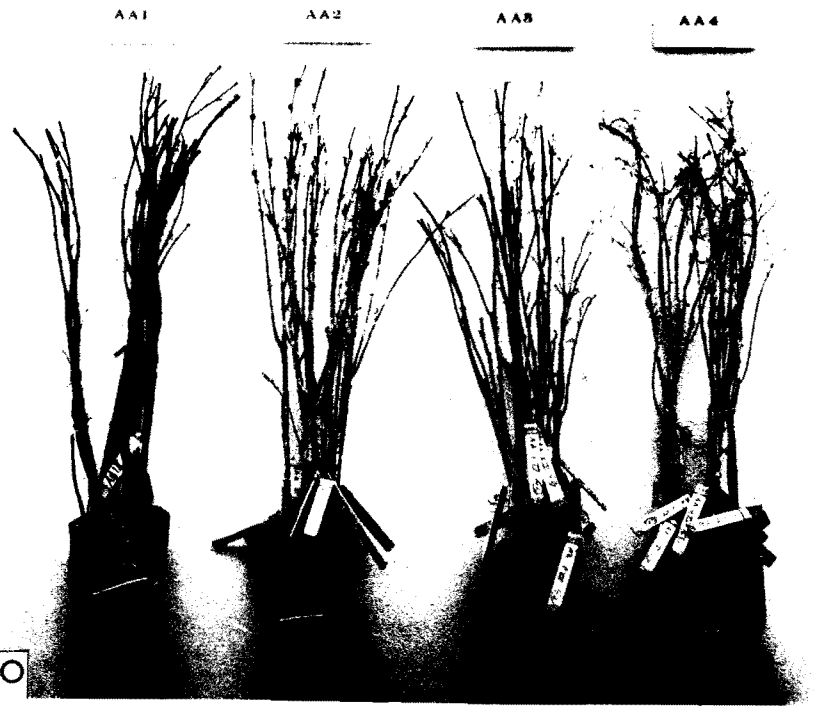
Root initial formation

The combined analysis of variance showed that there was no difference in root initial activity between the two species of elm. This response as influenced by the three root and/or stem environments is presented in Table 27. There was little variation between the two species packaged in similar environments as concerned root initial development. However, there were noticeable differences in response of the two species to the various treatments (Tables 28 and 29).

The effect of root treatments was the same for both species. As might be expected, root treatments making use of moist root packaging materials were those in which root initial development was found to be most profuse. Bare root

Figure 10. Seedlings of Ulmus americana, following storage. Stem treatments (left to right): waxed, ½ SP, 1½ SP, and 0 SP with a common root pack treatment (½ RP), consisting of ½ gallon of water per bushel of moss

Figure 11. Seedlings of Ulmus pumila, following storage. Stem treatments (left to right): waxed, ½ SP, 1½ SP, and 0 SP with a common root pack treatment (½ RP), consisting of ½ gallon of water per bushel of moss



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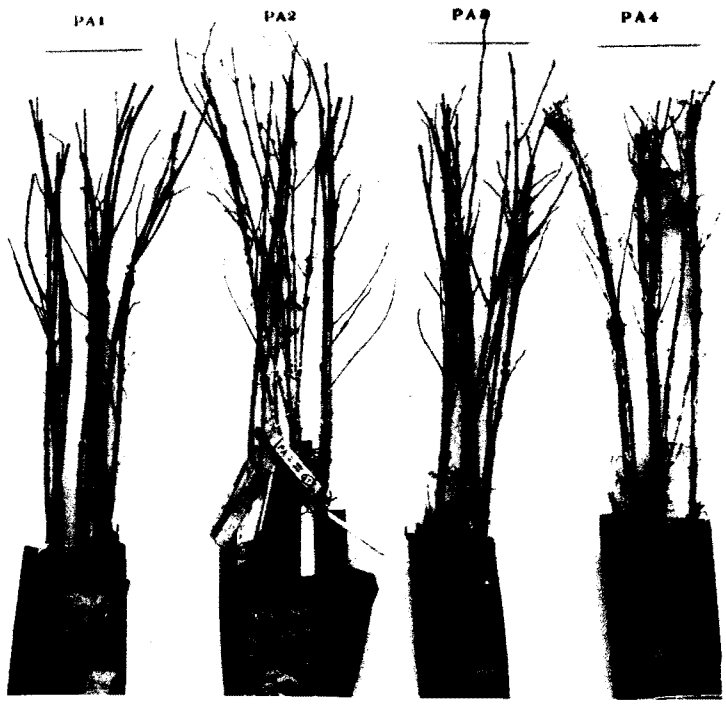

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Figure 12. Seedlings of Ulmus americana, following storage. Stem treatments (left to right): waxed, ½ SP, 1½ SP, and 0 SP with a common root pack treatment (1½ RP), consisting of 1½ gallons of water per bushel of moss

Figure 13. Seedlings of Ulmus pumila, following storage. Stem treatments (left to right): waxed, ½ SP, 1½ SP, and 0 SP with a common root pack treatment (1½ RP) consisting of 1½ gallons of water per bushel of moss

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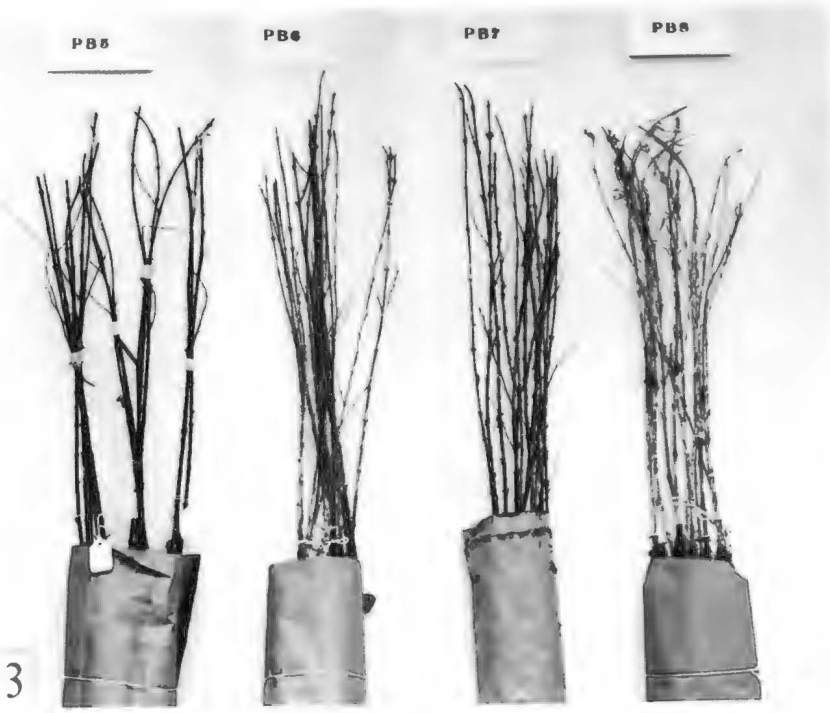

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Figure 14. Seedlings of Ulmus americana, following storage. Stem treatments (left to right): waxed, ½ SP, 1½ SP, and 0 SP with a common root pack treatment (0 RP), consisting of no treatment or bare root storage

Figure 15. Seedlings of Ulmus pumila, following storage. Stem treatments (left to right): waxed, ½ SP, 1½ SP, and 0 SP with a common root pack treatment (0 RP), consisting of no treatment or bare root storage

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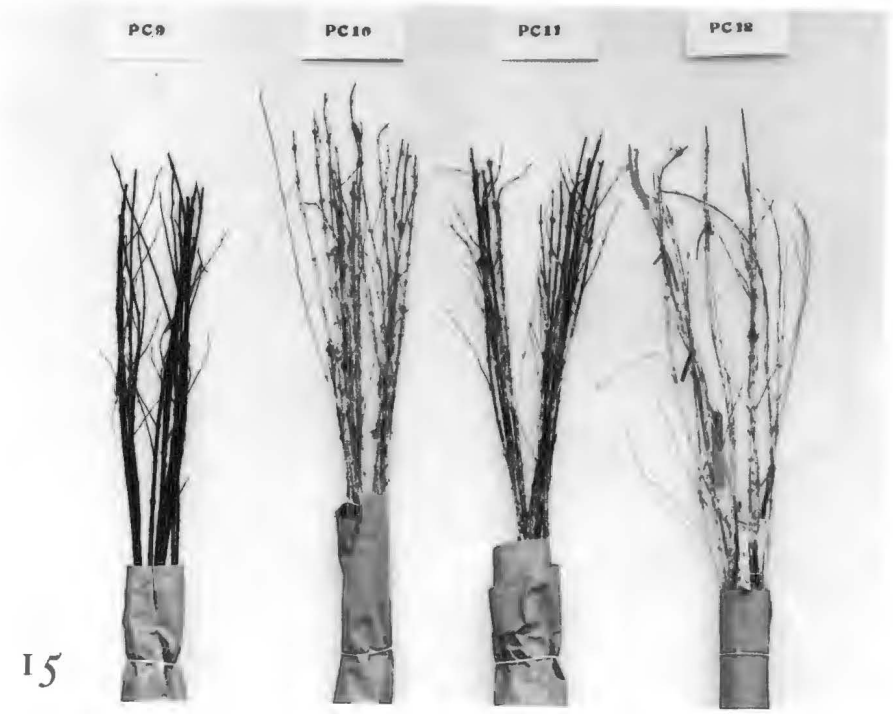

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Table 27. Ranking of root initial development as influenced by packaging environment

Treatment	*Ulmus americana*	*Ulmus pumila*	Difference in per cent
Root			
½ RP	48.7[a]	49.3[a]	1.22[b]
1½ RP	67.8	68.3	.74
0 RP	40.6	40.9	.73
Stem			
W	42.2	42.6	.94
½ SP	36.8	36.6	.54
1½ SP	45.0	46.0	1.28
0 SP	33.1	33.3	.06

[a]Total rank for all replications receiving the same packaging environment.

[b]Comparison of larger to smaller.

storage, even though the relative humidity of the surrounding environment approached 100 per cent, did not favor root activity. The 1½ RP treatment was most conducive to root initial development (Table 30).

Stem treatment effects were also considered to be no different between seedlings of the two species. The 1½ SP treatment and the 0 SP treatment was observed to be responsible for the two extremes in root initial development.

For seedlings of both species, with the exception of only one treatment combination, all treatments employing a packing material on the root portion maintained greater root initial activity than did the check seedlings (Tables 28 and 29). One treatment combination involving bare root storage

Table 28. Root initial development by ranks for seedlings of Ulmus americana

Treatment No.	Root	Stem	Total	Mean[a]	Comparison to check
1	½ RP	W	11.6	2.32	g[b]
2	½ RP	½ SP	10.9	2.18	
3	½ RP	1½ SP	16.2	3.24	G[c]
4	½ RP	0 SP	10.0	2.00	Check
5	1½ RP	W	20.0	4.00	G
6	1½ RP	½ SP	15.6	3.12	G
7	1½ RP	1½ SP	18.8	3.76	G
8	1½ RP	0 SP	13.4	2.68	G
9	0 RP	W	10.6	2.12	
10	0 RP	½ SP	10.3	2.06	
11	0 RP	1½ SP	10.0	2.00	
12	0 RP	0 SP	9.7	1.94	

Analysis of Variance

Source of variation	Degrees of freedom	Mean square	F
Total	59	.5235	
Treatments	11	2.6909	94.0874**
Root	2	9.7500	340.9090**
Stem	3	1.9000	66.4335**
Interaction	6	.7333	25.6398**
Replications	4	.0075	.2622
Error	44		

[a]Mean rank per plant; standard error of mean using generalized error, ± .08.

[b]g - significantly greater at 5 per cent level than check.

[c]G - significantly greater at 1 per cent level than check.

**Significant at 1 per cent level.

Table 29. Root initial development by ranks for seedlings of *Ulmus pumila*

No.	Treatment Root	Treatment Stem	Total	Mean[a]	Comparison to check
1	½ RP	W	12.0	2.40	G[b]
2	½ RP	½ SP	10.6	2.12	g[c]
3	½ RP	1½ SP	16.7	3.34	G
4	½ RP	0 SP	10.0	2.00	Check
5	1½ RP	W	20.0	4.00	G
6	1½ RP	½ SP	16.0	3.20	G
7	1½ RP	1½ SP	19.0	3.80	G
8	1½ RP	0 SP	13.3	2.66	G
9	0 RP	W	10.6	2.12	g
10	0 RP	½ SP	10.0	2.00	
11	0 RP	1½ SP	10.3	2.06	
12	0 RP	0 SP	10.0	2.00	

Analysis of Variance

Source of variation	Degrees of freedom	Mean square	F
Total	59	.0562	
Treatments	11	2.8009	518.6851**
Root	2	9.8500	1824.0740**
Stem	3	2.1933	406.1666**
Interaction	6	.7500	139.8148**
Replications	4	.0025	.4629
Error	44	.0054	

[a]Mean rank per plant; standard error of mean using generalized error, ± .03.

[b]G - significantly greater at 1 per cent level than check.

[c]g - significantly greater at 5 per cent level than check.

**Significant at 1 per cent level.

Table 30. Root initial development by ranks, test of least significant differences

Root treatment means				Stem treatment means			
Ulmus americana		Ulmus pumila		Ulmus americana		Ulmus pumila	
1½ RP	3.39	1½ RP	3.41	1½ SP	3.00	1½ SP	3.06
½ RP	2.43	½ RP	2.46	W	2.81	W	2.84
0 RP	2.03	0 RP	2.04	½ SP	2.45	½ SP	2.44
				0 SP	2.20	0 SP	2.22
L.S.D.		L.S.D.		L.S.D.		L.S.D.	
.05, .10		.05, .04		.05, .12		.05, .04	
.01, .14		.01, .05		.01, .16		.01, .06	

was found to have greater root initial activity than the check (Table 29). Considering both root and stem packaging treatments, the combinations using the 1½ g.p.b. moss, resulted in the greatest amount of root initial activity. Similarly, the least amount of root activity occurred with the bare root environment in combination with the untreated stem series.

Presence of mold

Mold activity on the seedlings used in these experiments was negligible for all treatments regardless of plant species. Visible activity of mold appeared only on seedlings in a few scattered replications. These were generally confined to those replications involving the higher moisture content sphagnum packs.

Since the mean rank of 1.0 represents complete freedom

from mold, it is obvious that mold development was not a problem (Table 31). Of interest was the fact that five treatments involving seedlings of Ulmus americana showed complete freedom from mold. The same observations were made for six of the treatments applied to seedlings of Ulmus pumila

Table 31. Mold growth by ranks

Treatment No.	Root	Stem	Ulmus americana Total	Ulmus americana Mean[a]	Ulmus pumila Total	Ulmus pumila Mean[b]
1	½ RP	W	5.0	1.00	5.0	1.00
2	½ RP	½ SP	5.6	1.12	5.3	1.06
3	½ RP	1½ SP	5.9	1.18	5.6	1.12
4	½ RP	0 SP	5.6	1.12	5.3	1.06
5	1½ RP	W	5.0	1.00	5.0	1.00
6	1½ RP	½ SP	5.9	1.18	5.0	1.00
7	1½ RP	1½ SP	6.2	1.24	6.0	1.20
8	1½ RP	0 SP	5.0	1.00	5.0	1.00
9	0 RP	W	5.0	1.00	5.0	1.00
10	0 RP	½ SP	5.3	1.06	5.0	1.00
11	0 RP	1½ SP	5.6	1.12	6.0	1.20
12	0 RP	0 SP	5.0	1.00	5.3	1.06

[a]Mean rank per plant; standard error of mean using generalized error, ± .06.

[b]Mean rank per plant; standard error of mean using generalized error, ± .07.

Even though the Least Significant Difference test, as well as the analysis of variance, showed significant differences between stem treatments of both species regarding mold activity, the fact is that the amount was not at a level approaching concern to the nurseryman. The fungi present on

infested plants were identified as species of Penicillum and Botrytis. In addition to these two types, Rhizopus was isolated on the bundle ties. Although some mold activity was encountered in storage, its growth and development was limited because of the fungicidal mixture employed, the waxing of plant stems, and/or the temperatures maintained in the storage.

Weight of plants prior to and following storage

The average weight of the American elm seedlings used in these experiments was 14.2 grams, with a range in weight from 9 to 16 grams. For seedlings of the Siberian elm, the average weight at the initiation of the experiment was found to be 13.8 grams, with a range from 8 to 16 grams.

Following the storage sequence, plants were re-weighed and found to be approximately the same as at the beginning of the storage experiment. Realizing that the seedlings involved could have lost or gained weight due to the packaging environment, the amounts were not large enough to be accurately determined.

FIELD EXPERIMENT

Purpose of the Study

The amount of information on the field performance of various species of elms following controlled storage is limited. It was the purpose of this experiment, therefore, to investigate the responses of the American and Siberian elms to known storage conditions, and to correlate these responses to field performance.

Materials and Method

Experimental design

The field test was laid out in completely randomized blocks with single group classification. This arrangement was designed so that the experimental material could be divided into groups, each of which would constitute a single replication.

For the field test, five blocks or replications were used. Each block consisted of the twelve treatment combinations for each of the three root and four stem environments provided for each species. All treatment combinations were randomized within each block. The five blocks were arranged in a continuous line, each block consisting of two rows, approximately thirty feet in length. The twelve treatments which were applied to each species consisted of three plants

per replication, with five replications of each individual treatment. There were a total of 72 plants in each block, or a total of 360 plants involved in the field experiment.

Data collected were analyzed by using a split plot design. The tests or significance between treatments were obtained through an analysis of variance. Originally, data for both of the species found in an entire block were combined into a joint analysis. However, the standard errors of the two species were found to be so unlike for some of the measurements that each species was later analyzed separately. For the test of either stem or root treatment effects, the test of least significant differences was used. In order to analyze overall treatment combination effects, the new multiple range test was employed. This test was useful to detect differences between treatments as a whole, but did not permit the identification of specific factors responsible for these differences. Data were recorded as the mean value per plant for the three plants included in any one replication.

Planting

Following the collection of the storage data, plants were removed from their respective packages and were root wrapped in moist sphagnum moss. The seedlings were then transplanted into nursery rows which had been prepared in

the customary manner, with plants being spaced 10 to 12 inches apart in the row. These rows were located near an overhead irrigation line so that the plots could be watered.

Soil tests

On July 1, and August 13, 1959, composite soil samples were collected and analyzed for pH, total soluble salts, and for levels of each particular nutrient. The pH of the soil solution was obtained from these samples by means of a Beckman pH meter (Model H-2). The total soluble salts were determined by a Solu-Bridge (Model RD-15), using a dilution ratio of 1:2 for soil and water. Soluble salt concentration was expressed as the specific conductance of the soil solution in micrchms per centimeter at 25°C. For the determination of specific elements, a modified Spurway analysis was employed. The plant nutrient levels were generally expressed as parts per million.

Sprout formation and development

After the seedlings had been in the experimental area for ten days, sprout data were recorded. These measurements consisted of the number of developing sprouts, the total linear growth of each sprout, the total linear development for all new branches, and the location of these sprouts and branches. The average length of all sprouts was later

calculated from these data.

Forty days after planting (thirty days after the first sprout measurements had been recorded on July 15), similar field measurements were obtained. At the conclusion of the growing period, when these species of elm would normally be dug for placement in storage, final growth measurements were recorded.

The number of sprouts was obtained by counting the number of new branches and/or branchlets that had developed from the original branch system. The original stem portion was divided into thirds and the number of new branches arising from each region was recorded.

Tree height and caliber

Tree height was recorded as the average height of each seedling. Caliber measurements were made with an Ilgenfritz Grader and recorded to the nearest one-sixteenth of an inch.

End number and development per unit stem length

It was noted that seedlings of Ulmus pumila produced approximately the same number of primary branches as Ulmus americana, although the proportion of secondary and tertiary branches was different. In order to determine the branching habit of each species, in relation to the diameter or caliber of the individual branches, a representative sample of each

species was selected. All branches were removed and separated into four arbitrary categories, based on diameter. For these determinations, ten inch sections of the branches were used and 25 sections for each caliber group were involved. The total number of buds present upon the section was recorded together with the percentages of the total number that had developed into branches.

Die-back

The amount of die-back was recorded as the per cent of the original stem system that remained alive or was green at the conclusion of the growing season. Stem portions were considered alive even if no new branches were produced from this region.

Moisture determinations of plant sections

Moisture determinations were made for stem and root sections by oven-drying the samples of the two species to a constant weight in a 100°C oven. Three root and stem sections from plants in all treatments and replications that were fall dug, were used for these determinations.

Dry weight of new growth

Since it appeared that the two species differed between treatments as to size and number of branches present, the

total dry weight of new stem growth was obtained from those replications dug in the fall. Following oven-drying, the dry weights of the samples were determined. The replications dug in the fall, and from which these dry weight determinations were obtained, included seedlings from blocks 1, 2, and 3.

Root development and winter survival

In order to obtain information on root development, winter survival, and growth responses the second growing season, blocks 4 and 5 were allowed to remain in the field overwinter. These plants were mulched with approximately four inches of straw, but otherwise were given no further protection during the winter months. On April 1, 1960, the two blocks were evaluated as to the number of live plants within each treatment and the number of large roots present on each plant. Only those new roots one-sixteenth inch or larger in diameter were considered in this determination.

Results and Discussion

Soil tests

Only the data for the August 13th sampling data are presented, since these results were essentially the same as those obtained earlier in the season. Soil tests indicated that none of the essential elements were found in the high

to excessive range.

Nutrients that were found to be in the normal range for maximum growth included the following elements: 1) nitrates (25 p.p.m.), 2) nitrites (negative), 3) available phosphorus (slightly below 5 p.p.m.), 4) available potassium (5 p.p.m.), 5) ammonium (trace), and 6) manganese (slightly greater than a trace). Those nutrients falling into the low to medium classification included: 1) available calcium (40 p.p.m.), 2) available magnesium (slightly below 10 p.p.m.), 3) sulphates (trace), 4) carbonates (trace), 5) chlorides (negative), 6) reserve iron (slightly below 2 p.p.m.), and 7) aluminum (negative). The soil pH ranged between 6.2 and 6.8. Soluble salt determinations ranged from 84 to 130 in specific conductance, with an average of 104. Both of these determinations are included in the normal range for maximum growth.

Since the data indicated that the soil was of average fertility, and differences between samples did not differ appreciably, it was concluded that responses derived from the experimental material were not biased.

Sprout formation and development

Following transplanting, all of the sprouts that had developed on the seedlings while in storage were completely burned off or were killed back. The amount of sprout development in storage, therefore, did not influence the

final results. The measurements, obtained ten days after transplanting (June 15, 1959), served as an index for determining the rate of establishment of seedlings, as well as an index for plant recovery.

Number of sprouts after ten days in the field Ten days after transplanting, records on the origin and amount of shoot growth were taken. Numbers of sprouts as related to the two species under investigation appear in Tables 32 and 33. The combined analysis of variance showed no difference between species, as related to the number of new sprouts, for this period of observation.

The three root environments applied to seedlings of Ulmus americana were no different in their effects upon the number of sprouts produced. Seedlings of Ulmus pumila that were stored bare root were observed to have significantly more new sprouts than those plants root wrapped in either of the two sphagnum packs. The ½ RP treatment and the 1½ RP treatment were no different (Table 34).

Both species responded similarly to the stem waxing treatment. These seedlings produced significantly more new sprouts than seedlings in any of the other three stem environments. The response from the remaining stem treatments varied with the treatment and with the species. For seedlings of Ulmus americana, the ½ and 1½ g.p.b. moss stem packs and the untreated stem treatment resulted in similar sprout produc-

Table 32. Number of sprouts on seedlings of Ulmus americana after ten days in the field

No.	Treatment Root	Stem	Total	Mean[a]	Comparison to check
1	½ RP	W	29.00	5.80 ± 1.23	
2	½ RP	½ SP	8.33	1.67 ± 1.59	
3	½ RP	1½ SP	14.66	2.93 ± 1.23	
4	½ RP	0 SP	12.00	2.40 ± 1.37	Check
5	1½ RP	W	45.00	9.00 ± 1.23	G[b]
6	1½ RP	½ SP	9.32	1.86 ± 1.37	
7	1½ RP	1½ SP	14.66	2.93 ± 1.37	
8	1½ RP	0 SP	18.67	3.73 ± 1.23	
9	0 RP	W	64.67	12.93 ± 1.23	G
10	0 RP	½ SP	5.34	1.07 ± 1.94	
11	0 RP	1½ SP	6.01	1.20 ± 1.59	
12	0 RP	0 SP	4.67	.93 ± 1.94	

Analysis of Variance

Source of variation	Degrees of freedom	Mean square	F
Total	59	18.3292	
Treatments	11	67.5491	8.9374**
Root	2	7.3927	.9781
Stem	3	194.6828	25.7585**
Interaction	6	24.0344	3.1799*
Blocks	4	1.4582	.1929
Error	44	7.5580	

[a]Mean value per plant; standard error of mean using generalized error.

[b]G - significantly greater at 1 per cent level than check.

**Significant at 1 per cent level.

*Significant at 5 per cent level.

Table 33. Number of sprouts on seedlings of Ulmus pumila after ten days in the field

No.	Treatment Root	Treatment Stem	Total	Mean[a]	Comparison to check
1	½ RP	W	42.01	8.40 ± 1.23	g[b]
2	½ RP	½ SP	12.34	2.47 ± 1.23	
3	½ RP	1½ SP	15.67	3.13 ± 1.23	
4	½ RP	0 SP	15.66	3.13 ± 1.38	Check
5	1½ RP	W	55.34	11.07 ± 1.23	G[c]
6	1½ RP	½ SP	5.33	1.07 ± 1.59	
7	1½ RP	1½ SP	6.00	1.20 ± 1.38	
8	1½ RP	0 SP	25.66	5.13 ± 1.23	
9	0 RP	W	73.00	14.60 ± 1.23	G
10	0 RP	½ SP	11.32	2.26 ± 1.38	
11	0 RP	1½ SP	20.00	4.00 ± 1.23	
12	0 RP	0 SP	31.33	6.27 ± 1.23	

Analysis of Variance

Source of variation	Degrees of freedom	Mean square	F
Total	59	22.9682	
Treatments	11	87.8804	11.2185**
Root	2	36.8153	4.6997*
Stem	3	272.8512	34.8313**
Interaction	6	12.4166	1.5850
Blocks	4	10.9411	1.3967
Error	44	7.8335	

[a]Mean value per plant; standard error of mean using generalized error.

[b]g - significantly greater at 5 per cent level than check.

[c]G - significantly greater at 1 per cent level than check.

**Significant at 1 per cent level.

*Significant at 5 per cent level.

Table 34. Number of sprouts after ten days in the field, test of least significant differences

Root treatment means				Stem treatment means			
Ulmus americana		Ulmus pumila		Ulmus americana		Ulmus pumila	
1½ RP	4.38	0 RP	6.78	W	9.24	W	11.35
0 RP	4.03	1½ RP	4.61	1½ SP	2.35	0 SP	4.84
½ RP	3.19	½ RP	4.28	0 SP	2.35	1½ SP	2.77
				½ SP	1.53	½ SP	1.93
L.S.D.		L.S.D.		L.S.D.		L.S.D.	
.05, 1.75		.05, 1.78		.05, 2.02		.05, 2.05	
.01 2.33		.01, 2.38		.01, 2.70		.01, 2.75	

tion. For seedlings of Ulmus pumila, the series of stems receiving no treatment produced more new sprouts than either the seedlings in the ½ SP or the 1½ SP treatments. There was no difference in response between the two sphagnum packs (Table 34).

The treatment combination(s) responsible for the greatest number of new sprouts on seedlings of Ulmus americana were those combining stem waxing with any one of the three root environments (Table 34). The treatment responsible for the most sprouting, regardless of variety, was stem waxing in conjunction with bare root storage (Tables 32 and 33). Ulmus pumila seedlings, in all three treatment combinations employing the wax stem dip, were found to produce significantly more sprouts than those in the check treatment. With seedlings of Ulmus americana, the treatment combinations employing the wax stem dip, in conjunction with both the 1½ SP and bare

root storage treatments, resulted in more sprouting than produced by the check treatment (Tables 32 and 33).

The fact that waxed seedlings remained dormant in storage without appreciable loss of moisture supports the observation that dormant seedlings generally outperform seedlings which have flushed in storage. Seedlings of Ulmus americana, stored bare root without stem protection, were observed to be completely dormant at the end of the storage period. These, however, produced only a small number of new sprouts ten days after field planting. Even though these plants were dormant at the end of the storage experiment, internal conditions which were possibly associated with some root-stem interaction, may have resulted in the poor performance of these seedlings in the field.

Total linear growth ten days after field planting

The combined analysis of variance revealed that linear development after ten days in the field was the same for the American and Siberian elm seedlings. However, individual analysis of the data showed differential treatment effects (Tables 35 and 36).

Treatments which resulted in the greatest number of new sprouts were also those which produced the greatest amount of linear growth. This was observed for seedlings of both species.

Treatment combinations involving the wax stem dip were

Table 35. Total linear growth ten days after field planting for seedlings of Ulmus americana

No.	Treatment Root	Treatment Stem	Total	Mean[a]	Comparison to check
1	½ RP	W	36.56	7.31 ± 1.48	g[b]
2	½ RP	½ SP	9.39	1.87 ± 1.91	
3	½ RP	1½ SP	22.11	4.42 ± 1.48	
4	½ RP	0 SP	13.85	2.77 ± 1.65	Check
5	1½ RP	W	62.25	12.45 ± 1.48	G[c]
6	1½ RP	½ SP	8.12	1.52 ± 1.65	
7	1½ RP	1½ SP	15.42	3.08 ± 1.65	
8	1½ RP	0 SP	16.52	3.30 ± 1.48	
9	0 RP	W	85.48	17.09 ± 1.48	G
10	0 RP	½ SP	2.12	.42 ± 2.34	
11	0 RP	1½ SP	5.19	1.03 ± 1.91	
12	0 RP	0 SP	1.50	.30 ± 2.34	

Analysis of Variance

Source of variation	Degrees of freedom	Mean square	F
Total	59	33.7171	
Treatments	11	135.1579	12.3747**
Root	2	5.2812	.4835
Stem	3	395.4862	36.2097**
Interaction	6	48.2861	4.4209**
Blocks	4	5.4989	.5034
Error	44	10.9221	

[a]Mean value per plant; standard error of mean using generalized error; measurements in centimeters.

[b]g - significantly greater at 5 per cent level than check.

[c]G - significantly greater at 1 per cent level than check.

**Significant at 1 per cent level.

Table 36. Total linear growth ten days after field planting for seedlings of Ulmus pumila

No.	Treatment Root	Treatment Stem	Total	Mean[a]	Comparison to check
1	½ RP	W	36.64	7.30 ± 1.30	g[b]
2	½ RP	½ SP	5.91	1.18 ± 1.30	
3	½ RP	1½ SP	5.78	1.15 ± 1.30	
4	½ RP	0 SP	9.29	1.85 ± 1.45	Check
5	1½ RP	W	52.15	10.43 ± 1.30	G[c]
6	1½ RP	½ SP	2.79	.55 ± 1.67	
7	1½ RP	1½ SP	1.68	.33 ± 1.45	
8	1½ RP	0 SP	14.75	2.94 ± 1.30	
9	0 RP	W	69.16	13.83 ± 1.30	G
10	0 RP	½ SP	6.02	1.20 ± 1.45	
11	0 RP	1½ SP	9.69	1.93 ± 1.30	
12	0 RP	0 SP	31.60	6.23 ± 1.30	G

Analysis of Variance

Source of variation	Degrees of freedom	Mean square	F
Total	59	24.7505	
Treatments	11	97.0194	11.5296**
Root	2	47.3970	5.6325**
Stem	3	299.8308	35.6313**
Interaction	6	12.1544	1.4444
Blocks	4	5.7037	.6778
Error	44	8.4148	

[a]Mean value per plant; standard error of mean using generalized error; measurements in centimeters.

[b]g - significantly greater at 5 per cent level than check.

[c]G - significantly greater at 1 per cent level than check.

**Significant at 1 per cent level.

found to result in significantly more linear growth than that produced by the check treatments of both species (Tables 35 and 36). In addition to these three treatments, the treatment combination consisting of the untreated stem series and bare root storage was also found to have more linear growth than seedlings of Ulmus pumila included in the check (Tables 36 and 37).

Table 37. Total linear growth ten days after field planting, test of least significant differences

Root treatment means				Stem treatment means			
Ulmus americana		Ulmus pumila		Ulmus americana		Ulmus pumila	
1½ RP	5.11	0 RP	5.82	W	12.28	W	10.53
0 RP	4.71	1½ RP	3.56	1½ SP	2.84	0 SP	3.70
½ RP	4.09	½ RP	2.88	0 SP	2.12	1½SP	1.14
				½ SP	1.30	½ SP	.98
L.S.D.		L.S.D.		L.S.D.		L.S.D.	
.05, 2.10		.05, 1.84		.05, 2.43		.05, 2.13	
.01, 2.81		.01, 2.46		.01, 3.24		.01, 2.85	

Number of new sprouts, final growth The combined analysis of variance showed that seedlings of Ulmus pumila produced significantly more new sprouts than seedlings of Ulmus americana. The effect of the root packaging treatment on bud break or sprout development was quite uniform between species (Table 38). Although Ulmus pumila produced 80 per cent or more sprouts than seedlings of Ulmus americana, the differences between the three root package environments were

Table 38. Total number of sprouts at conclusion of growing season as influenced by packaging environment

Treatment	Ulmus pumila	Ulmus americana	Difference in per cent
Root			
½ RP	2640.7[a]	426.1[a]	83.86[b]
1½ RP	3167.7	413.7	86.94
0 RP	3222.0	405.2	87.42
Stem			
W	2741.6	489.1	82.16
½ SP	2251.1	215.3	90.44
1½ SP	2101.0	276.3	86.85
0 SP	1936.7	264.3	86.35

[a]Total number of sprouts for all replications receiving the same packaging environment.

[b]Comparison of larger to smaller.

less than 4 per cent. Stem waxing resulted in the least variation between species in so far as new sprout development was concerned (Table 38). Data pertaining to the individual performance for the two species are presented in Tables 39 and 40.

Root treatments had no differential effect on the number of new sprouts produced by Ulmus americana seedlings during the first growing season. For seedlings of Ulmus pumila, the root environments employing the 1½ RP and bare root storage were found to be conducive to the production of a greater number of new sprouts than was produced by seedlings included in the ½ RP treatment (Table 41).

For the effect of stem treatments, the wax stem dip

Table 39. Number of sprouts at conclusion of growing season on seedlings of Ulmus americana

No.	Treatment Root	Stem	Total	Mean[a]	Comparison to check
1	½ RP	W	108.6	21.72	
2	½ RP	½ SP	71.6	14.32	s[b]
3	½ RP	1½ SP	132.6	26.52	
4	½ RP	0 SP	113.3	22.66	Check
5	1½ RP	W	168.4	33.68	G[c]
6	1½ RP	½ SP	84.3	16.86	
7	1½ RP	1½ SP	82.3	16.46	
8	1½ RP	0 SP	78.7	15.74	
9	0 RP	W	212.1	42.42	G
10	0 RP	½ SP	59.4	11.88	S[d]
11	0 RP	1½ SP	61.4	12.28	S
12	0 RP	0 SP	72.3	14.46	s

Analysis of Variance

Source of variation	Degrees of freedom	Mean square	F
Total	59	104.2205	
Treatments	11	438.5363	16.4697**
Root	2	5.5200	.2073**
Stem	3	983.6166	36.9408**
Interaction	6	310.2000	11.6499**
Blocks	4	38.5850	1.4491
Error	44	26.6268	

[a]Mean value per plant; standard error of mean using generalized error, ± 2.31.

[b]s - significantly smaller at 5 per cent level than check.

[c]G - significantly greater at 1 per cent level than check.

[d]S - significantly smaller at 1 per cent level than check.

**Significant at 1 per cent level.

Table 40. Number of sprouts at conclusion of growing season on seedlings of Ulmus pumila

Treatment No.	Root	Stem	Total	Mean[a]	Comparison to check
1	½ RP	W	738.9	147.78	
2	½ RP	½ SP	518.7	103.74	
3	½ RP	1½ SP	730.7	146.14	
4	½ RP	0 SP	652.4	130.48	Check
5	1½ RP	W	975.7	195.14	G[b]
6	1½ RP	½ SP	796.0	159.20	
7	1½ RP	1½ SP	702.0	140.40	
8	1½ RP	0 SP	694.0	138.80	
9	0 RP	W	1027.0	205.40	G
10	0 RP	½ SP	936.4	187.28	g[c]
11	0 RP	1½ SP	668.3	133.66	
12	0 RP	0 SP	590.3	118.06	

Analysis of Variance

Source of variation	Degrees of freedom	Mean square	F
Total	59	1868.5098	
Treatments	11	4828.9736	4.1258**
Root	2	5154.8900	4.4042*
Stem	3	8039.9700	6.8692**
Interaction	6	3114.8366	2.6612*
Blocks	4	1406.1975	1.2014
Error	44	1170.4222	

[a]Mean value per plant; standard error of mean using generalized error, ± 15.30.

[b]G - significantly greater at 1 per cent level than check.

[c]g - significantly greater at 5 per cent level than check.

**Significant at 1 per cent level.

*Significant at 5 per cent level.

Table 41. Number of sprouts at conclusion of growing season, test of least significant differences

Root treatment means				Stem treatment means			
Ulmus americana		Ulmus pumila		Ulmus americana		Ulmus pumila	
½ RP	21.30	0 RP	161.10	W	32.60	W	182.77
1½ RP	20.68	1½ RP	158.38	1½ SP	18.42	½ SP	150.07
0 RP	20.26	½ RP	132.03	0 SP	17.62	1½ SP	140.06
				½ SP	14.35	0 SP	129.11
L.S.D.		L.S.D.		L.S.D.		L.S.D.	
.05, 3.28		.05, 21.79		.05, 3.79		.05, 26.29	
.01, 4.39		.01, 29.11		.01, 5.07		.01, 33.61	

again resulted in the greatest number of new sprouts, regardless of species. Although the sphagnum stem packs and the untreated stem series were found to result in a similar response for seedlings of Ulmus pumila, this did not hold true for seedlings of Ulmus americana. For the latter species, the 1½ SP treatment resulted in the production of a greater number of sprouts than the ½ SP treatment (Table 41).

As was the case with earlier sprout measurements, seedlings which remained relatively dormant in storage were found to be those which produced the greatest number of new breaks. The only exception to this occurred with seedlings of Ulmus americana which were stored without root or stem protection. The fact that seedlings of Ulmus pumila had more original branches, as well as a greater number of buds per given stem area, apparently explains why this species produced more sprouts the first growing season.

Total linear growth after one growing season Combining the total linear growth for all seedlings involved in the twelve treatment combinations, Siberian elm seedlings produced 71.91 per cent more growth than seedlings of the American elm (Table 42). There was little variation between species

Table 42. Total linear growth at conclusion of first growing season as influenced by packaging environment

Treatment	Ulmus americana	Ulmus pumila	Difference in per cent
Root			
½ RP	279.5[a]	1139.7[a]	75.47[b]
1½ RP	296.8	1346.6	77.96
0 RP	274.5	1364.6	79.89
Stem			
W	387.4	1226.7	68.42
½ SP	146.4	944.4	84.50
1½ SP	161.9	893.6	81.88
0 SP	155.1	786.2	80.28

[a]Total linear growth for all replications receiving the same packaging environment; measurements in feet.

[b]Comparison of larger to smaller.

as influenced by the three root environments. However, a wide range of differences was observed between stem treatments applied to seedlings of the two species. Data for the individual performance of the American and Siberian elms appear in Tables 43 and 44.

Linear growth at this period was similar to earlier observations in that the seedlings which had the greatest

Table 43. Total linear growth at conclusion of first growing season for seedlings of Ulmus americana

No.	Treatment Root	Stem	Total	Mean[a]	Comparison to check
1	½ RP	W	86.8	17.36	
2	½ RP	½ SP	51.4	10.28	
3	½ RP	1½ SP	72.2	14.44	
4	½ RP	0 SP	69.1	13.82	Check
5	1½ RP	W	132.8	26.56	G[b]
6	1½ RP	½ SP	56.7	11.34	
7	1½ RP	1½ SP	57.8	11.56	
8	1½ RP	0 SP	49.5	9.90	
9	0 RP	W	167.8	33.56	G
10	0 RP	½ SP	38.3	7.66	
11	0 RP	1½ SP	31.9	6.38	S[c]
12	0 RP	0 SP	36.5	7.30	

Analysis of Variance

Source of variation	Degrees of freedom	Mean square	F
Total	59	80.2413	
Treatments	11	335.5918	16.3013**
Root	2	6.8485	.3326
Stem	3	906.9831	44.0565**
Interaction	6	159.4800	7.7467**
Blocks	4	34.2275	1.6625
Error	44	80.2413	

[a]Mean value per plant; standard error of mean using generalized error, ± 4.01; measurements in feet.

[b]G - significantly greater at 1 per cent level than check.

[c]S - significantly smaller at 1 per cent level than check.

**Significant at 1 per cent level.

Table 44. Total linear growth at conclusion of first growing season for seedlings of Ulmus pumila

No.	Treatment Root	Stem	Total	Mean[a]	Comparison to check
1	½ RP	W	319.7	63.94	
2	½ RP	½ SP	220.5	44.10	
3	½ RP	1½ SP	324.9	64.98	
4	½ RP	0 SP	274.6	54.92	Check
5	1½ RP	W	453.4	90.68	G[b]
6	1½ RP	½ SP	315.3	63.06	
7	1½ RP	1½ SP	282.2	56.44	
8	1½ RP	0 SP	295.7	59.14	
9	0 RP	W	453.6	90.72	G
10	0 RP	½ SP	408.6	81.72	g[c]
11	0 RP	1½ SP	286.5	57.30	
12	0 RP	0 SP	215.9	43.18	

Analysis of Variance

Source of variation	Degrees of freedom	Mean square	F
Total	59	401.5605	
Treatments	11	1263.1009	6.2026**
Root	2	780.9300	3.8348*
Stem	3	2354.6200	11.5627**
Interaction	6	878.0650	4.3118*
Blocks	4	209.4600	1.0285
Error	44	203.6390	

[a]Mean value per plant; standard error of mean using generalized error, ± 6.38; measurements in feet.

[b]G - significantly greater at 1 per cent level than check.

[c]g - significantly greater at 5 per cent level than check.

**Significant at 1 per cent level.

*Significant at 5 per cent level.

number of sprouts were those which produced the greatest amount of growth (Table 45). Since seedlings of Ulmus pumila produce more sprouts, the species also produced the greatest amount of linear growth.

Table 45. Total linear growth at conclusion of first growing season, test of least significant differences

Root treatment means				Stem treatment means			
Ulmus americana		Ulmus pumila		Ulmus americana		Ulmus pumila	
1½ RP	14.84	0 RP	68.23	W	25.82	W	81.78
½ RP	13.97	1½ RP	67.33	1½ SP	10.79	½ SP	62.96
0 RP	13.72	½ RP	56.98	0 SP	10.34	1½ SP	59.57
				½ SP	9.76	0 SP	52.14
L.S.D.		L.S.D.		L.S.D.		L.S.D.	
.05, 2.89		.05, 9.09		.05, 3.33		.05, 10.49	
.01, 3.86		.01, 12.14		.01, 4.45		.01, 14.02	

Average sprout length, final growth Although seedlings of Ulmus americana were observed to have fewer sprouts than seedlings of Ulmus pumila, the average length of these sprouts was 35.38 per cent greater than those produced by seedlings of Ulmus pumila.

The data comparing average sprout length for seedlings packaged in similar stem and root environments are presented in Table 46 for the two species. Treatment effects for the seedlings of both the American and Siberian elms appear in Tables 47 and 48.

Of the three root treatments employed, bare root storage

Table 46. Total of the average sprout lengths at conclusion of growing season as influenced by packaging environment

Treatment	Ulmus americana	Ulmus pumila	Difference in per cent
Root			
½ RP	163.4[a]	105.8[a]	32.25[b]
1½ RP	167.2	101.8	39.11
0 RP	146.5	100.7	31.36
Stem			
W	142.7	80.6	43.52
½ SP	122.1	77.3	36.69
1½ SP	106.8	76.5	28.38
0 SP	105.5	73.9	29.95

[a]Total of the average lengths for all replications receiving the same packaging environment; measurements in inches.

[b]Comparison of larger to smaller.

resulted in seedlings having the shortest lateral growth, regardless of species. Ulmus pumila seedlings packed in the ½ RP treatment were found to produce longer sprouts than the seedlings stored either bare root or in the 1½ RP treatment. Ulmus americana seedlings contained in the two sphagnum root packs behaved similarly in relation to the sprout length (Table 49).

American elm seedlings which had been waxed produced longer sprouts than any of the seedlings stored in the other stem environments. Also, the ½ SP treatment was conducive to the production of longer sprouts than either the untreated stem series or those receiving the 1½ SP treatments.

Table 47. Average sprout length at conclusion of growing season for seedlings of Ulmus americana

Treatment No.	Root	Stem	Total	Mean[a]	Comparison to check
1	½ RP	W	46.9	9.38	G[b]
2	½ RP	½ SP	44.9	8.98	
3	½ RP	1½ SP	33.5	6.70	
4	½ RP	0 SP	38.9	7.62	Check
5	1½ RP	W	48.1	9.62	G
6	1½ RP	½ SP	40.0	8.00	
7	1½ RP	1½ SP	41.8	8.36	
8	1½ RP	0 SP	37.3	7.46	
9	0 RP	W	47.7	9.54	G
10	0 RP	½ SP	37.2	7.44	
11	0 RP	1½ SP	31.5	6.30	
12	0 RP	0 SP	30.1	6.02	s[c]

Analysis of Variance

Source of variation	Degrees of freedom	Mean square	F
Total	59	2.1889	
Treatments	11	7.8236	8.7600**
Root	2	6.0712	6.7978**
Stem	3	20.0464	22.4458**
Interaction	6	2.2967	2.5716*
Blocks	4	.9475	1.0609
Error	44	.8931	

[a]Mean value per plant; standard error of mean using generalized error, ± .42; measurements in inches.

[b]G - significantly greater at 1 per cent level than check.

[c]s - significantly smaller at 5 per cent level than check.

**Significant at 1 per cent level.

*Significant at 5 per cent level.

Table 48. Average sprout length at conclusion of growing season for seedlings of Ulmus pumila

Treatment No.	Root	Stem	Total	Mean[a]	Comparison to check
1	½ RP	W	26.2	5.24	
2	½ RP	½ SP	26.5	5.30	
3	½ RP	1½ SP	27.0	5.40	g[b]
4	½ RP	0 SP	26.1	5.22	Check
5	1½ RP	W	27.9	5.58	G[c]
6	1½ RP	½ SP	24.0	4.80	S[d]
7	1½ RP	1½ SP	24.2	4.84	S
8	1½ RP	0 SP	25.7	5.14	
9	0 RP	W	26.5	5.30	
10	0 RP	½ SP	26.8	5.36	
11	0 RP	1½ SP	25.3	5.06	S
12	0 RP	0 SP	22.1	4.42	S

Analysis of Variance

Source of variation	Degrees of freedom	Mean square	F
Total	59	.1659	
Treatments	11	.5036	5.2788**
Root	2	.3600	3.7735*
Stem	3	.5100	5.3459**
Interaction	6	.5483	5.7473**
Blocks	4	.0125	.1310
Error	44	.0954	

[a]Mean value per plant; standard error of mean using generalized error, ± .14; measurements in inches.

[b]g - significantly greater at 5 per cent level than check.

[c]G - significantly greater at 1 per cent level than check.

[d]S - significantly smaller at 1 per cent level than check.

**Significant at 1 per cent level.

Table 49. Average sprout length at conclusion of growing season, test of least significant differences

Root treatment means				Stem treatment means			
Ulmus americana		Ulmus pumila		Ulmus americana		Ulmus pumila	
1½ RP	8.36	½ RP	5.29	W	9.51	W	5.37
½ RP	8.17	1½ RP	5.09	½ SP	8.14	½ SP	5.15
0 RP	7.32	0 RP	5.03	1½ SP	7.12	1½ SP	5.10
				0 SP	7.03	0 SP	4.92
L.S.D.		L.S.D.		L.S.D.		L.S.D.	
.05, .60		.05, .19		.05, .69		.05, .22	
.01, .80		.01, .26		.01, .92		.01, .30	

Seedlings of Ulmus pumila which had been waxed produced longer sprouts than plants in either the 1½ SP or untreated stem series. Comparing these latter two treatments, the seedlings contained in the 1½ SP treatment produced the longest sprouts (Table 49). A comparison of the treatment combination effects showed considerable variation (Tables 47 and 48).

A comparison of sprout number, average length of sprouts, and the total length of growth produced by seedlings at the end of the growing season showed that these three measurements are not necessarily related. For example, stem treatments applied to seedlings of Ulmus pumila resulted in proportional measurements for sprout number, average length of sprouts, and total growth. Considering the effect of root treatments on these same measurements, results showed that bare root storage was responsible for the greatest amount of sprouting and total growth. The average length of these sprouts, how-

ever, were the shortest produced by seedlings in any one root treatment (Tables 41, 45, and 49). Similar comparisons for Ulmus americana can also be made. The point to be considered is that there is no consistent relationship between sprout number, average sprout length, and total linear growth as mediated by any one treatment.

Origin of sprout development In general, the seedlings produced new growth from the distal portion of the branch system portion of the stems. The two species were similar in response to basal bud break according to the combined analysis of variance. The individual analysis of data, however, showed that differences existed as the result of the application of various packaging treatments. These differences were generally associated with stem treatment effects rather than with the root environments employed (Tables 50 and 51).

Stem waxing, for both species, was found to be responsible for the largest number of seedlings which produced sprouts from the region included in the basal one-third portion of the plant (Table 52). While no differences were found between those stem treatments not involving the wax dip, for seedlings of Ulmus pumila, plants of Ulmus americana packaged in the 1½ SP treatment produced more breaks from the basal region than those in the untreated stem series.

Since die-back of the original branches was less for

Table 50. Number of Ulmus americana seedlings sprouting from the basal one-third of the plant

No.	Treatment Root	Treatment Stem	Total	Mean[a]	Comparison to check
1	½ RP	W	13	2.60 ± .30	G[b]
2	½ RP	½ SP	5	1.00 ± .34	
3	½ RP	1½ SP	6	1.20 ± .34	
4	½ RP	0 SP	3	.60 ± .39	Check
5	1½ RP	W	11	2.20 ± .30	G
6	1½ RP	½ SP	2	.40 ± .47	
7	1½ RP	1½ SP	5	1.00 ± .39	
8	1½ RP	0 SP	3	.60 ± .47	
9	0 RP	W	14	2.80 ± .30	G
10	0 RP	½ SP	4	.80 ± .39	
11	0 RP	1½ SP	6	1.20 ± .34	
12	0 RP	0 SP	2	.40 ± .67	

Analysis of Variance

Source of variation	Degrees of freedom	Mean square	F
Total	59	1.0633	
Treatments	11	3.5218	7.8436**
Root	2	.5200	1.1581**
Stem	3	12.2000	27.1714**
Interaction	6	.1833	.4082
Blocks	4	1.0600	2.3608
Error	44	.4490	

[a]Mean number of plants per replication; standard error of mean using generalized error.

[b]G - significantly greater at 1 per cent level than check.

**Significant at 1 per cent level.

Table 51. Number of Ulmus pumila seedlings sprouting from the basal one-third of the plant

No.	Treatment Root	Stem	Total	Mean[a]	Comparison to check
1	½ RP	W	14	2.80 ± .36	g[b]
2	½ RP	½ SP	3	.60 ± .58	
3	½ RP	1½ SP	5	1.00 ± .41	
4	½ RP	0 SP	6	1.20 ± .36	Check
5	1½ RP	W	11	2.20 ± .36	
6	1½ RP	½ SP	6	1.20 ± .47	
7	1½ RP	1½ SP	5	1.00 ± .47	
8	1½ RP	0 SP	3	.60 ± .47	
9	0 RP	W	10	2.00 ± .36	
10	0 RP	½ SP	4	.80 ± .47	
11	0 RP	1½ SP	6	1.20 ± .41	
12	0 RP	0 SP	1	.20 ± .81	

Analysis of Variance

Source of variation	Degrees of freedom	Mean square	F
Total	59	1.0294	
Treatments	11	2.7945	4.2257**
Root	2	.6200	.9375
Stem	3	8.4666	12.8029**
Interaction	6	.6833	1.0332
Blocks	4	.2250	.3402
Error	44	.6613	

[a]Mean number of plants per replication; standard error of mean using generalized error.

[b]g - significantly greater at 5 per cent level than check.

**Significant at 1 per cent level.

Table 52. Number of seedlings sprouting from the basal one-third of the plant, test of least significant differences

Root treatment means				Stem treatment means			
Ulmus americana		Ulmus pumila		Ulmus americana		Ulmus pumila	
½ RP	1.35	½ RP	1.40	W	2.53	W	2.33
0 RP	1.30	1½ RP	1.25	1½ SP	1.13	1½ SP	1.06
1½ RP	1.05	0 RP	1.05	½ SP	.73	½ SP	.86
				0 SP	.53	0 SP	.66
L.S.D.		L.S.D.		L.S.D.		L.S.D.	
.05, .42		.05, .51		.05, .49		.05, .59	
.01, .56		.01, .69		.01, .65		.01, .79	

those stems which had been dipped in wax, this could not have been the result of the destruction of apical dominance by the wax treatment. Because waxing tended to retard bud development, the physiology of the plant could have been modified so that a more even bud break resulted. The majority of waxed plants formed branches from the lower one-third region; whereas only a limited number of seedlings for the other treatment combinations were observed to respond in this manner. It was noted earlier that waxing also was responsible for greater numbers of new sprouts and a greater amount of linear development. Although this response would result in the production of an increased photosynthetic area and a more vigorous plant during the early life of the tree, removal of these lower limbs would be necessary later if it were used for ornamental planting.

Tree height and caliber

Tree height Considering the combined analysis of variance, there was no difference in height between the two species of elms under investigation. However, the individual analysis of variance for the treatments involved showed a differential species response (Tables 53 and 54).

Bare root storage treatments resulted in the production of the smallest trees, regardless of species. Root wrapping with moist sphagnum moss generally favored the production of the tallest trees. For the effect of stem treatments, trees which were unprotected during storage grew the least, while seedlings of both species receiving the wax stem dip were found to have grown the most (Table 55). The three treatment combinations responsible for plants larger than the check seedlings of either species made use of the wax dip as the common stem treatment (Tables 53 and 54).

Although there were trees of each species that were taller or equal in height to the seedlings included in the wax stem treatments, the greater average plant height was maintained between replications. This response was attributed to the greater uniformity of seedlings, to the fact that waxed trees began growth earlier, and to the fact that they became established sooner than the other treatment combinations employed. Seedlings that were taller than those which had been waxed generally had fewer new branches.

Table 53. Height of Ulmus americana seedlings at the conclusion of the first growing season

Treatment No.	Root	Stem	Total	Mean[a]	Comparison to check
1	½ RP	W	255	51.0	g[b]
2	½ RP	½ SP	240	48.0	
3	½ RP	1½ SP	223	44.6	
4	½ RP	0 SP	210	42.0	Check
5	1½ RP	W	253	50.6	g
6	1½ RP	½ SP	230	46.0	
7	1½ RP	1½ SP	221	44.2	
8	1½ RP	0 SP	217	43.4	
9	0 RP	W	256	51.2	g
10	0 RP	½ SP	202	40.4	
11	0 RP	1½ SP	192	38.4	
12	0 RP	0 SP	156	31.2	S[c]

Analysis of Variance

Source of variation	Degrees of freedom	Mean square	F
Total	59	49.8516	
Treatments	11	171.1681	7.5738**
Root	2	234.6500	10.3827**
Stem	3	386.8600	17.1176**
Interaction	6	42.1616	1.8655
Blocks	4	16.0000	.7079
Error	44	22.6000	

[a]Mean value per plant; standard error of mean using generalized error, ± 2.13; measurements in inches.

[b]g - significantly greater at 5 per cent level than check.

[c]S - significantly smaller at 1 per cent level than check.

**Significant at 1 per cent level.

Table 54. Height of Ulmus pumila seedlings at the conclusion of the first growing season

No.	Treatment Root	Treatment Stem	Total	Mean[a]	Comparison to check
1	½ RP	W	245	49.0	g[b]
2	½ RP	½ SP	236	47.2	
3	½ RP	1½ SP	216	43.2	
4	½ RP	0 SP	212	42.4	Check
5	1½ RP	W	256	51.2	G[c]
6	1½ RP	½ SP	233	46.6	
7	1½ RP	1½ SP	225	45.0	
8	1½ RP	0 SP	208	41.6	
9	0 RP	W	273	54.6	G
10	0 RP	½ SP	213	42.6	
11	0 RP	1½ SP	195	39.0	
12	0 RP	0 SP	175	35.0	s[d]

Analysis of Variance

Source of variation	Degrees of freedom	Mean square	F
Total	59	40.6472	
Treatments	11	143.9808	8.2844**
Root	2	61.1200	3.3167*
Stem	3	393.9733	22.6685**
Interaction	6	46.6050	2.6815
Blocks	4	12.4225	.7147
Error	44	17.3797	

[a]Mean value per plant; standard error of mean using generalized error, ± 1.86; measurements in inches.

[b]g - significantly greater at 5 per cent level than check.

[c]G - significantly greater at 1 per cent level than check.

[d]s - significantly smaller at 5 per cent level than check.

**Significant at 1 per cent level.

*Significant at 5 per cent level.

Table 55. Height of seedlings at conclusion of the first growing season, test of least significant differences

Root treatment means				Stem treatment means			
Ulmus americana		Ulmus pumila		Ulmus americana		Ulmus pumila	
½ RP	46.40	1½ RP	46.10	W	50.93	W	51.60
1½ RP	46.05	½ RP	45.45	½ SP	44.80	½ SP	45.46
0 RP	40.30	0 RP	42.80	1½ SP	42.40	1½ SP	42.40
				0 SP	38.86	0 SP	39.66
L.S.D.		L.S.D.		L.S.D.		L.S.D.	
.05, 3.02		.05, 2.62		.05, 3.49		.05, 3.06	
.01, 4.04		.01, 3.54		.01, 4.67		.01, 4.09	

Caliber determinations The caliber measurements for the two species of elm under study followed the same general pattern as concerns response to a particular treatment or treatment combination (Tables 56 and 57).

Root treatment effects were alike for both species in that no differences between the three root environments were present. Bare root storage resulted in seedlings having the smallest caliber. The sphagnum root pack resulted in seedlings which produced the greatest caliber (Table 58). Stem treatment effects were also alike for both species in that stem waxing produced seedlings with the largest caliber. Treatment combinations employing the wax stem dip were observed to be the only treatments producing seedlings with consistently good caliber.

Seedlings which were waxed did not consistently have a larger caliber than those in the other treatment combinations.

Table 56. Caliber determinations of Ulmus americana seedlings

No.	Treatment Root	Stem	Total	Mean[a]	Comparison to check
1	¼ RP	W	40.3	8.06	G[b]
2	¼ RP	¼ SP	31.6	6.32	
3	¼ RP	1¼ SP	31.0	6.18	
4	¼ RP	0 SP	31.7	6.34	Check
5	1¼ RP	W	40.6	8.12	G
6	1¼ RP	¼ SP	31.6	6.32	
7	1¼ RP	1¼ SP	30.9	6.18	
8	1¼ RP	0 SP	32.0	6.40	
9	0 RP	W	41.0	8.20	G
10	0 RP	¼ SP	29.0	5.80	
11	0 RP	1¼ SP	30.1	6.02	
12	0 RP	0 SP	31.1	6.22	

Analysis of Variance

Source of variation	Degrees of freedom	Mean square	F
Total	59	1.0794	
Treatments	11	3.9281	9.5807**
Root	2	.2250	.5487
Stem	3	14.0260	34.2097**
Interaction	6	.1133	.2763
Blocks	4	.5350	1.3048
Error	44	.4100	

[a]Mean value per plant; standard error of mean using generalized error, ± .29; measurements in sixteenths of an inch.

[b]G - significantly greater at 1 per cent level than check.

**Significant at 1 per cent level.

Table 57. Caliber determinations of Ulmus pumila seedlings

Treatment No.	Root	Stem	Total	Mean[a]	Comparison to check
1	½ RP	W	41.3	8.26	G[b]
2	½ RP	½ SP	32.3	6.46	
3	½ RP	1½ SP	32.9	6.58	
4	½ RP	0 SP	32.3	6.46	Check
5	1½ RP	W	41.3	8.26	G
6	1½ RP	½ SP	32.0	6.40	
7	1½ RP	1½ SP	32.4	6.48	
8	1½ RP	0 SP	32.4	6.48	
9	0 RP	W	40.0	8.00	G
10	0 RP	½ SP	30.1	6.02	
11	0 RP	1½ SP	29.0	5.80	
12	0 RP	0 SP	31.4	6.28	

Analysis of Variance

Source of variation	Degrees of freedom	Mean square	F
Total	59	.9172	
Treatments	11	3.7390	14.7553**
Root	2	1.0600	4.1831*
Stem	3	12.8033	50.5260**
Interaction	6	.1000	.3946
Blocks	4	.4600	1.8153
Error	44	.2534	

[a]Mean value per plant; standard error of mean using generalized error, ± .23; measurements in sixteenths of an inch.

[b]G - significantly greater at 1 per cent level than check.

**Significant at 1 per cent level.

*Significant at 5 per cent level.

Table 58. Caliber determinations at conclusion of first growing season, test of least significant differences

Root treatment means				Stem treatment means			
Ulmus americana		Ulmus pumila		Ulmus americana		Ulmus pumila	
1½ RP	6.75	½ RP	6.94	W	8.12	W	8.17
½ RP	6.73	1½ RP	6.90	0 SP	6.32	0 SP	6.40
0 RP	6.56	0 RP	6.52	½ SP	6.14	½ SP	6.29
				1½ SP	6.13	1½ SP	6.28
L.S.D.		L.S.D.		L.S.D.		L.S.D.	
.05, .40		.05, .32		.05, .47		.05, 1.17	
.01, .54		.01, .42		.01, .62		.01, 1.56	

Although variation occurred in all replications, this variation was consistently greater for seedlings in the non-waxed treatments.

Bud number and development per unit stem length

Regardless of caliber, stem sections of Ulmus pumila had nearly twice the number of buds per section as contrasted to comparable sections of Ulmus americana. Considering the overall number of buds observed on these ten inch sections, Ulmus pumila had 40.89 per cent more buds than did Ulmus americana. The difference in the number of buds that had developed into branches was even more noticeable. There was 99 per cent greater development of the buds on the Siberian elm seedlings in comparison to the seedlings of the American elm. The majority of branches found on Ulmus americana were single, straight, and unbranched shoots; whereas, in the case

of Ulmus pumila, there was pronounced branching due primarily to this increased bud development (Table 59).

This increased bud development, in addition to having more buds per given unit of stem and a greater number of original branches, accounts for the greater linear growth,

Table 59. Bud number and development per ten inch section[a]

Caliber of stem (inches)	Ulmus americana		Ulmus pumila	
	Number present	Number developed	Number present	Number developed
1/16	13.3	.00	20.9	5.8
2/16	10.8	.20	20.5	9.8
3/16	12.4	.00	19.1	14.5
4/16	11.4	.30	20.5	13.2
Average	12.0	.01	20.3	10.8

[a]Mean value of 25 sections for each caliber group.

number of new sprouts, and the increased dry weight production of the new growth for seedlings of the Siberian elm. Although there were these differences in bud activity, there was no appreciable difference in the ultimate height of the seedlings at the conclusion of the first growing season.

Die-back

At the end of the first growing season, it was evident that some of the stem treatments applied in storage had in-

fluenced the amount of die-back sustained by the original stem systems of the seedlings (Tables 60, 61, and 62). For both species, stem waxing treatments resulted in the least amount of die-back, while seedlings which had been stored without stem protection showed the greatest amount of this type of injury. The untreated stem series resulted in a smaller percentage of original stem survival than the other stem treatments involved (Table 62). Treatment combinations involving stem waxing, in conjunction with all of the root environments, were found to result in less die-back than check seedlings of Ulmus americana (Table 60). The treatment combination consisting of bare root storage, in conjunction with the untreated stem series, maintained a smaller percentage of original stems surviving than the check seedlings of Ulmus pumila. On the other hand, the stem wax dip, in combination with both the higher moisture content root pack and bare root storage, resulted in greater stem survival than for seedlings included in the check (Table 62).

Moisture determinations of plant sections

It was not known whether the higher moisture content observed in stem and root sections of Ulmus pumila was normal or whether it was possibly due to the treatment that the seedlings received prior to their purchase from the commercial nursery. In order to investigate this point, stem and root

Table 60. Die-back of Ulmus americana seedlings following storage and one growing season

No.	Treatment Root	Treatment Stem	Total	Mean[a]	Comparison to check
1	½ RP	W	486.6	97.32	g[b]
2	½ RP	½ SP	466.3	93.26	
3	½ RP	1½ SP	467.0	93.40	
4	½ RP	0 SP	460.2	92.04	Check
5	1½ RP	W	483.8	96.76	g
6	1½ RP	½ SP	470.1	94.02	
7	1½ RP	1½ SP	474.0	94.80	
8	1½ RP	0 SP	462.9	92.58	
9	0 RP	W	483.7	96.74	g
10	0 RP	½ SP	469.3	93.86	
11	0 RP	1½ SP	466.4	93.28	
12	0 RP	0 SP	445.8	89.16	

Analysis of Variance

Source of variation	Degrees of freedom	Mean square	F
Total	59	11.4054	
Treatments	11	26.1209	3.0959**
Root	2	8.2650	.9796
Stem	3	81.2333	9.6282**
Interaction	6	4.5166	.5353
Blocks	4	3.5900	.4255
Error	44	8.4370	

[a]Mean value per plant; standard error of mean using generalized error, ± 1.30; measurements in per cent of original stem portion remaining alive.

[b]g - significantly greater at 5 per cent level than check.

**Significant at 1 per cent level.

Table 61. Die-back of Ulmus pumila seedlings following storage and one growing season

Treatment No.	Root	Stem	Total	Mean[a]	Comparison to check
1	¼ RP	W	478.9	95.78	
2	¼ RP	½ SP	465.6	93.12	
3	¼ RP	1½ SP	473.3	94.66	
4	¼ RP	0 SP	457.6	91.52	Check
5	1½ RP	W	482.2	96.44	G[b]
6	1½ RP	½ SP	464.3	92.86	
7	1½ RP	1½ SP	475.3	95.06	
8	1½ RP	0 SP	458.2	91.64	
9	0 RP	W	483.8	96.76	G
10	0 RP	½ SP	470.6	94.12	
11	0 RP	1½ SP	467.0	93.40	
12	0 RP	0 SP	435.8	87.16	S[c]

Analysis of Variance

Source of variation	Degrees of freedom	Mean square	F
Total	59	13.4123	
Treatments	11	34.8863	4.0296**
Root	2	7.2700	.8397
Stem	3	101.3866	16.0161**
Interaction	6	10.8416	1.2522
Blocks	4	6.6625	.7695
Error	44	8.6575	

[a]Mean value per plant; standard error of mean using generalized error, ± 1.32; measurements in per cent of original stem portion remaining alive.

[b]G - significantly greater at 1 per cent level than check.

[c]S - significantly smaller at 1 per cent level than check.

**Significant at 1 per cent level.

Table 62. Die-back following storage and one growing season, test of least significant differences

Root treatment means						Stem treatment means					
Ulmus americana			Ulmus pumila			Ulmus americana			Ulmus pumila		
1½	RP	94.54	1½	RP	94.00	W		96.94	W		96.32
½	RP	94.00	½	RP	93.77	1½	SP	93.82	1½	SP	94.37
0	RP	93.26	0	RP	92.86	½	SP	93.71	½	SP	93.36
						0	SP	91.26	0	SP	90.10
L.S.D.			L.S.D.			L.S.D.			L.S.D.		
.05, 1.85			.05, 1.87			.05, 2.13			.05, 2.16		
.01, 2.47			.01, 2.50			.01, 2.85			.01, 2.89		

sections were taken from both species of elm at the time when they would normally have been dug in the fall. Moisture content determinations were made on these samples.

All determinations from the root and stem portions, for each treatment combination employed, were included in an overall mean moisture percentage value. This was done since there were no basic differences between moisture percentages as influenced by treatment effect for the 36 root or stem sections of a particular species. No great difference occurred for either the root or stem sections at this sampling period, although a wider range of variation between samples was encountered. A comparison of original moisture percentages and those determined following one growing season appears in Table 63.

Mean values for stem sections more nearly approach the original determinations than do the root sections. The wider

Table 63. Original moisture determinations compared to those following one growing season

Period of determination	Ulmus americana		Ulmus pumila	
	Mean	Range	Mean	Range
		Stem sections		
Original determination	46.33	43.45-49.43	51.45	47.51-54.54
Following field growth	45.82	41.41-50.02	51.88	45.38-56.32
		Root sections		
Original determination	54.34	52.11-57.36	62.62	58.15-66.26
Following field growth	56.28	48.22-60.33	65.02	59.31-69.88

range of variation between comparable sections at this time may have resulted because the plant parts were not held in a controlled environment long enough to permit them to reach equilibrium.

The rate of moisture loss from untreated sections was determined from fresh material. As observed previously, three-fourths of the total weight loss of stem and root sections of Ulmus pumila occurred in three days. A similar response for sections of Ulmus americana took place in two and one-half days. Moisture content of stem and root sections of both species was again determined after the plants had been placed in a refrigerated storage, following the completion of the field experiment. Determinations at three, six, and nine week intervals revealed that the moisture percentages were nearly the same as obtained the previous year and that

all were included within the moisture range exhibited by the plants prior to storage.

Dry weight of new growth

The dry weight of all new growth produced during the first growing season by any one root or stem environment for seedlings of Ulmus americana was found to be directly proportional to the total linear growth. For seedlings of Ulmus pumila, the range from the largest to the smallest amount of linear growth, as a result of stem treatments, was due to stem waxing and to those stems receiving no treatment. However, for stem treatment effects as related to dry weight production, the waxed stem dip and the ½ SP treatments were observed to have produced the largest and smallest dry weights, respectively. Root treatment effects were the same as those responsible for total linear growth (Tables 64 and 65).

Both the combined and individual analysis of variance showed no differences between lots of seedlings treated alike in regard to their performance in the field. There is no reason to suspect that the dry weight of the growth produced by seedlings in the three replications involved in these determinations would differ from the seedlings included in the entire population. Bare root storage of Ulmus americana seedlings resulted in the smallest dry weight of new growth,

Table 64. Dry weight of new growth for seedlings of Ulmus americana

Treatment No.	Root	Stem	Total	Mean[a]	Comparison to check
1	½ RP	W	49.3	16.43	
2	½ RP	½ SP	33.1	11.03	
3	½ RP	1½ SP	61.1	20.36	
4	½ RP	0 SP	59.9	19.96	Check
5	1½ RP	W	78.3	26.10	
6	1½ RP	½ SP	50.3	16.76	
7	1½ RP	1½ SP	52.2	17.40	
8	1½ RP	0 SP	31.7	10.56	
9	0 RP	W	107.0	35.66	G[b]
10	0 RP	½ SP	20.2	6.73	S[c]
11	0 RP	1½ SP	28.0	9.33	
12	0 RP	0 SP	32.9	10.96	

Analysis of Variance

Source of variation	Degrees of freedom	Mean square	F
Total	35	78.9848	
Treatments	11	198.7927	8.3138**
Root	2	12.6700	.5298
Stem	3	371.5600	15.5393**
Interaction	6	174.4500	7.2958**
Blocks	2	25.8550	1.0813
Error	22	23.9109	

[a]Mean value per plant; standard error of mean using generalized error, ± 2.82; measurements in grams.

[b]G - significantly greater at 1 per cent level than check.

[c]S - significantly smaller at 1 per cent level than check.

**Significant at 1 per cent level.

Table 65. Dry weight of new growth for seedlings of Ulmus pumila

Treatment No.	Root	Stem	Total	Mean[a]	Comparison to check
1	½ RP	W	73.6	24.53	
2	½ RP	½ SP	50.2	16.73	
3	½ RP	1½ SP	80.4	26.80	
4	½ RP	0 SP	89.6	29.86	Check
5	1½ RP	W	124.3	41.43	
6	1½ RP	½ SP	74.4	24.80	
7	1½ RP	1½ SP	92.3	30.76	
8	1½ RP	0 SP	76.3	25.43	
9	0 RP	W	129.7	43.23	
10	0 RP	½ SP	96.7	32.23	
11	0 RP	1½ SP	73.1	24.36	
12	0 RP	0 SP	74.7	29.40	

Analysis of Variance

Source of variation	Degrees of freedom	Mean square	F
Total	35	91.8248	
Treatments	11	167.6463	3.0294*
Root	2	165.4700	2.9901**
Stem	3	245.9233	4.4439**
Interaction	6	129.2333	2.3353
Blocks	2	76.1500	1.3760
Error	22	55.3390	

[a]Mean value per plant; standard error of mean using generalized error, ± 4.30; measurements in grams.

*Significant at 5 per cent level.

**Significant at 1 per cent level.

while the same root treatment resulted in the largest dry weight for seedlings of Ulmus pumila. Although this was true, no differences were found to result from the three root environments provided for seedlings of the American elm (Table 66). For seedlings of Ulmus pumila, bare root storage favored the production of new growth which resulted in a greater dry weight than for those seedlings stored in the ½ RP treatment (Table 66). Stem treatments were alike in

Table 66. Dry weight of new growth, test of least significant differences

Root treatment means				Stem treatment means			
Ulmus americana		Ulmus pumila		Ulmus americana		Ulmus pumila	
1½ RP	17.70	0 RP	31.18	W	26.06	W	36.40
½ RP	16.95	1½ RP	30.60	1½ SP	15.70	1½ SP	27.31
0 RP	15.67	½ RP	24.48	0 SP	13.83	0 SP	26.73
				½ SP	11.51	½ SP	24.58
L.S.D.		L.S.D.		L.S.D.		L.S.D.	
.05, 4.14		.05, 6.29		.05, 4.78		.05, 7.27	
.01, 5.62		.01, 8.56		.01, 6.49		.01, 9.88	

their influence upon dry weight production of both species included in this experiment. Seedlings which had been waxed produced more growth which had a greater dry weight than any of the plants included in the other stem treatments. No differences were found to exist between either of the sphagnum stem packs and the untreated stem series (Table 66).

For treatment combination effects, check seedlings of

Ulmus pumila were found to be no different from any of the treatments employed (Table 65). For seedlings of Ulmus americana, the wax stem dip and bare root storage treatment resulted in significantly more growth, which had a greater dry weight than seedlings included in the check (Table 64).

Root development and winter survival

Root development A combined analysis showed that there were no differences between seedlings of the two species as related to the number of new roots produced that were 1/16 inch or larger in diameter. Differences may be observed between species, however, when the treatment effects are analyzed individually (Tables 67 and 68). Root treatment effects were alike for both species in that the greatest number of new roots of the largest caliber were found associated with the 1½ RP storage treatment. The fewest numbers of new roots were found to be the result of bare root storage of the seedlings (Table 69). No differences in new root numbers existed between the seedlings of Ulmus americana stored in the sphagnum packs and those stored bare root (Table 69). Only seedlings of the Siberian elm which had been stored in the higher moisture pack produced more new roots than the bare root storage treatment (Table 69). The results of the stem treatment involving the wax stem dip were found to be similar for both species in that this treatment resulted

Table 67. Number of new roots produced by seedlings of *Ulmus americana*[a]

Treatment No.	Root	Stem	Total	Mean[b]	Comparison to check
1	½ RP	W	19.0	9.50	g[c]
2	½ RP	½ SP	10.0	5.00	
3	½ RP	1½ SP	10.6	5.30	
4	½ RP	0 SP	11.0	5.50	Check
5	1½ RP	W	19.7	9.85	g
6	1½ RP	½ SP	7.7	3.85	
7	1½ RP	1½ SP	12.0	6.00	
8	1½ RP	0 SP	12.7	6.35	
9	0 RP	W	19.6	9.80	g
10	0 RP	½ SP	5.0	2.50	
11	0 RP	1½ SP	11.4	5.70	
12	0 RP	0 SP	4.0	2.00	s[d]

Analysis of Variance

Source of variation	Degrees of freedom	Mean square	F
Total	23	7.8017	
Treatments	11	13.8727	6.9145**
Root	2	5.4350	2.7089**
Stem	3	41.4800	20.6748**
Interaction	6	2.8816	1.4362
Blocks	1	4.7700	2.3775
Error	11	2.0063	

[a] 1/16 inch or larger in diameter.

[b] Mean value per plant; standard error of mean using generalized error, ± 1.00.

[c] g - significantly greater at 5 per cent level than check.

[d] s - significantly smaller at 5 per cent level than check.

** Significant at 1 per cent level.

Table 68. Number of new roots produced by seedlings of *Ulmus pumila*[a]

Treatment No.	Root	Stem	Total	Mean[b]	Comparison to check
1	½ RP	W	19.4	9.70	g[c]
2	½ RP	½ SP	10.4	5.00	
3	½ RP	1½ SP	10.7	5.35	
4	½ RP	0 SP	10.4	5.20	Check
5	1½ RP	W	21.0	10.50	G[d]
6	1½ RP	½ SP	10.0	5.00	
7	1½ RP	1½ SP	11.0	5.50	
8	1½ RP	0 SP	9.4	4.70	
9	0 RP	W	21.7	10.85	G
10	0 RP	½ SP	6.7	3.35	
11	0 RP	1½ SP	6.3	3.15	
12	0 RP	0 SP	5.0	2.50	

Analysis of Variance

Source of variation	Degrees of freedom	Mean square	F
Total	23	8.6252	
Treatments	11	16.3163	9.9605**
Root	2	5.2950	3.2324**
Stem	3	53.0933	32.6105**
Interaction	6	1.6016	.9777
Blocks	1	.8800	.5372
Error	11	1.6381	

[a] 1/16 inch or larger in diameter.

[b] Mean value per plant; standard error of mean using generalized error, ± .91.

[c] g - significantly greater at 5 per cent level than check.

[d] G - significantly greater at 1 per cent level than check.

** Significant at 1 per cent level.

Table 69. Number of new roots 1/16 inch or larger, test of least significant differences[a]

Root treatment means				Stem treatment means			
Ulmus americana		Ulmus pumila		Ulmus americana		Ulmus pumila	
1½ RP	6.51	1½ RP	6.42	W	9.71	W	10.35
½ RP	6.32	½ RP	6.31	1½ SP	5.66	1½ SP	4.66
0 RP	5.00	0 RP	4.96	0 SP	4.61	½ SP	4.45
				½ SP	3.78	0 SP	4.13
L.S.D.		L.S.D.		L.S.D.		L.S.D.	
.05, 1.55		.05, 1.40		.05, 1.79		.05, 1.62	
.01, 2.19		.01, 1.98		.01, 2.53		.01, 2.29	

[a]1/16 inch or larger in diameter.

in the production of more new roots than any of the other stem environments. Although no differences were found to be present between the sphagnum stem packs and the untreated stem series for seedlings of Ulmus pumila, seedlings of Ulmus americana stored in the 1½ SP treatment were found to have a greater number of new roots than the ½ SP treatment (Table 69).

For combination effects, seedlings which had been waxed, regardless of the root treatment applied in storage produced more roots than the check seedlings. Seedlings of Ulmus americana, which had not been protected in storage produced less roots than the seedlings in the control treatment (Table 67).

Winter survival Although only two blocks of seedlings were involved in the winter survival study, it was felt that

the information obtained in this respect would be indicative of the results that would be obtained in an experiment involving larger numbers of seedlings. Winter survival can be considered to be no different between seedlings of the two species, according to the combined analysis of variance.

The survival of Ulmus americana seedlings, according to the individual analysis of variance, was not found to be influenced by either the root or stem storage treatments (Table 70). However, in testing for the specific effects of either stem and/or root treatments differences due to stem treatment were found to be present (Table 71). For seedlings of both species, stem treatment effects were alike in that plants which had been waxed gave the highest survival readings, while those which had been stored without the wax dip or the moist packing materials gave the poorest stands. Also the higher moisture content sphagnum pack (1½ SP), was less conducive to successful overwintering than the ½ SP treatment (Table 72). It is of interest to note that all seedlings, regardless of species, which were waxed maintained 100 per cent survival (Tables 70 and 71). Seedlings of Ulmus americana that were stored without stem protection had more winter mortality than those which had been waxed or stem packed in sphagnum moss (Table 71). In general, seedlings which had been stored in a sphagnum root pack were those which had the best survival overwinter.

Table 70. Winter survival of *Ulmus americana* seedlings

Treatment No.	Root	Stem	Per cent survival	Mean[a]	Comparison to check
1	½ RP	W	100.0	3.00	g[b]
2	½ RP	½ SP	100.0	3.00	g
3	½ RP	1½ SP	100.0	3.00	g
4	½ RP	0 SP	83.3	2.50	Check
5	1½ RP	W	100.0	3.00	g
6	1½ RP	½ SP	100.0	3.00	g
7	1½ RP	1½ SP	83.3	2.50	
8	1½ RP	0 SP	66.7	2.00	
9	0 RP	W	100.0	3.00	g
10	0 RP	½ SP	83.3	2.50	
11	0 RP	1½ SP	83.3	2.50	
12	0 RP	0 SP	50.0	1.50	

Analysis of Variance

Source of variation	Degrees of freedom	Mean square	F
Total	23	.4186	
Treatments	11	.4663	1.2451
Root	2	.5000	1.3351
Stem	3	1.1533	3.0795
Interaction	6	.1116	.2979
Blocks	1	.3800	1.0146
Error	11	.3745	

[a]Mean number surviving per replication; standard error of mean using generalized error, ± .43.

[b]g - significantly greater at 5 per cent level than check.

Table 71. Winter survival of Ulmus pumila seedlings

Treatment No.	Root	Stem	Per cent survival	Mean[a]	Comparison to check
1	½ RP	W	100.0	3.00	
2	½ RP	½ SP	100.0	3.00	
3	½ RP	1½ SP	100.0	3.00	
4	½ RP	0 SP	83.3	2.50	Check
5	1½ RP	W	100.0	3.00	
6	1½ RP	½ SP	100.0	3.00	
7	1½ RP	1½ SP	100.0	3.00	
8	1½ RP	0 SP	66.7	2.00	
9	0 RP	W	100.0	3.00	
10	0 RP	½ SP	83.3	2.50	
11	0 RP	1½ SP	50.0	1.50	
12	0 RP	0 SP	16.7	.50	S[b]

Analysis of Variance

Source of variation	Degrees of freedom	Mean square	F
Total	23	.6956	
Treatments	11	1.2727	7.0005**
Root	2	2.3750	13.0638**
Stem	3	2.1100	11.6061**
Interaction	6	.4866	.2676
Blocks	1	.0000	.0000
Error	11	.1818	

[a]Mean number surviving per replication; standard error of mean using generalized error, ± .30.

[b]S - significantly smaller at 1 per cent level than check.

**Significant at 1 per cent level.

Table 72. Winter survival, test of least significant differences

Root treatment means				Stem treatment means			
Ulmus americana		Ulmus pumila		Ulmus americana		Ulmus pumila	
½ RP	2.87	½ RP	2.87	W	3.00	W	3.00
1½ RP	2.62	1½ RP	2.75	½ SP	2.83	½ SP	2.83
0 RP	2.37	0 RP	1.87	1½ SP	2.66	1½ SP	2.50
				0 SP	2.00	0 SP	1.66
L.S.D.		L.S.D.		L.S.D.		L.S.D.	
.05, .67		.05, .46		.05, .77		.05, .54	
.01, .95		.01, .66		.01, 1.09		.01, .76	

Miscellaneous observations

At the conclusion of the growing season it was observed that the stems of some of the seedlings which had been waxed had what appeared to be a trace of a waxy deposit. The presence of wax was primarily associated with the less vigorous trees. In no case was wax present in such quantities that it was detectable except by the waxy feel on the original stem portion of the plant. The presence of this waxiness was due to the fact that an occasional tree had not grown as rapidly as the others, and as a result, had not sluffed off all of the original wax. Even though the presence of this wax was extremely hard to detect on the more vigorous trees, it appeared significant that the greater percentage of the trees that survived the winter involved the stem waxing treatment. Whether waxing influenced winter survival or whether greater plant survival was attributable to better

establishment and/or field growth cannot be resolved in this study.

It was also observed that the Siberian elm was slow to defoliate in comparison to the American species. Even though seedlings of the Ulmus americana seedlings were completely defoliated at the time of the first killing frost, the seedlings of Ulmus pumila still retained the majority of their leaves. It was not until late November that seedlings of Ulmus pumila lost all of their leaves, suggesting that the growth period of this species is of longer duration than for Ulmus americana. This longer period of active growth is further substantiated by the fact that seedlings of Ulmus pumila seemingly break their period of rest sooner in the spring.

STARCH AND ANATOMICAL STUDY

Purpose of the Study

Plant maturity is one of the most important factors influencing the successful storage of nursery stock. Since the starch test described by Lyle[1] provided a positive method for determining plant maturity, it was used to determine whether the two species of elms under investigation differed in respect to the accumulation of starch at various intervals during the storage and handling sequences.

Anatomical comparisons were also made between the two species in order to determine if structural differences existed which might account for the variation in moisture content, the rate of moisture loss, and the difference in respiratory activity. Stems which had been waxed were also sectioned in order to determine if waxing might have caused any damage to the tissue systems of the branches.

Materials and Method

Representative samples for these determinations were selected from seedlings contained in the surplus package for each treatment combination in the storage experiment. Root

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[1]Lyle, E. W. Tyler, Texas. Texas Rose Research Foundation, Inc. Information on staining techniques as related to maturity tests. Private communication. 1958.

and stem cross sections were 35 microns in thickness and were made on a rotary microtome without embedding in a supporting matrix.

An iodine solution was used to determine the concentration of starch granules in the sections. This solution contained the following materials:

.5 gram iodine crystals
1.5 grams potassium iodide crystals
50.0 cubic centimeters distilled water
50.0 cubic centimeters glycerine.

In order to evaluate the relative maturity of the tissues and distribution of food reserves as influenced by the length of storage, stained cross sections of either roots or stems were classified in one of four categories, as follows:

1. trace of starch within the section
2. starch distributed along the entire length of the medullary ray system
3. starch accumulation in the pith and xylem of the cross section
4. starch granules distributed throughout the cross section

As a quantitative measurement of the amount of starch contained in the various tissues, the number of cells which approached complete staining were counted. Five determinations were made for each cross section. The total area

covered by each determination was .35 square millimeters. In addition to direct counting of the cells which contained starch granules, polarized light was used to determine the concentration of starch contained in each section. The degree of staining was also studied by means of a photometer which recorded the transmission of light through the various samples.

Results and Discussion

Starch content

The method of four group ranking, when used as a measure of maturity and of food reserve, showed little variation between the two species. All sections were ranked in category 4, in which the starch granules were distributed throughout the cross section. This method of evaluation, since it considers only the distribution of starch and not the amount contained in the various tissue systems, is of little use as a test to establish differences in maturity or distribution of food reserves during the storage sequence. From these sections however, it was apparent that, regardless of the date of sampling, the cambial region of stem sections of Ulmus americana generally had a greater accumulation of starch than the cambial region of Ulmus pumila. A greater concentration of starch appeared in the cortical region of the roots of the Siberian elm than in the root sections of the American

elm. When stem and root sections were made at final storage, tissues exterior to the cortex and exterior to the endodermis in the roots were quite soft and subject to breakage. Root sections of Ulmus pumila were more heavily stained in the endodermal region than were those of Ulmus americana. The greater starch content of the stem sections, as evidenced by the more intense staining, was generally concentrated in the pith and the area surrounding the medullary rays (Figures 16 through 19).

Quantitative determinations (Table 73), showed that

Table 73. Starch content of sections prior to and following storage

Plant species	Section	Prior to storage		Following storage	
		Mean[a]	Range	Mean[b]	Range
Ulmus americana	stem	71.7	53-107	69.3	54-101
Ulmus pumila	stem	58.9	45-83	59.2	47-80
Ulmus americana	root	215.6	190-230	210.7	193-222
Ulmus pumila	root	90.6	71-120	88.8	76-114

[a]Mean value for 25 sections.

[b]Mean value for 3 sections per treatment combination.

there was little or no difference in the starch content of the stem and root sections of a particular species as influenced by length of storage. The two species, however, differed in the amount of starch located in the various tissues systems and organs. Root sections of Ulmus americana were

Figure 16. Cross section of a stem of Ulmus americana stained with iodine for starch determinations (x50)

Note starch concentration around pith and within medullary rays

Figure 17. Cross section of a stem of Ulmus pumila stained with iodine for starch determinations (x50)

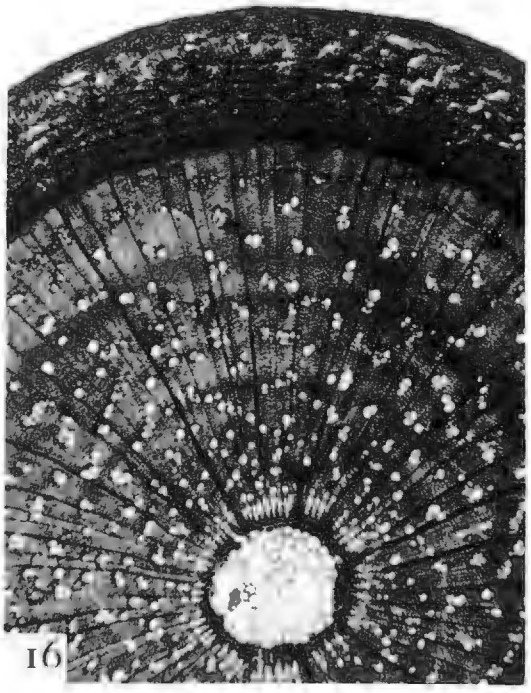
Note starch concentration around pith and within medullary rays and the crushing of cortical tissue

Figure 18. Cross section of a root of Ulmus americana stained with iodine for starch determinations (x50)

Note starch concentration internal to the endodermis and abundance of starch filled cells

Figure 19. Cross section of a root of Ulmus pumila stained with iodine for starch determinations (x50)

Note intense staining in the endodermal region, and the staining of vascular area as compared to the root section of Ulmus americana (Figure 18)



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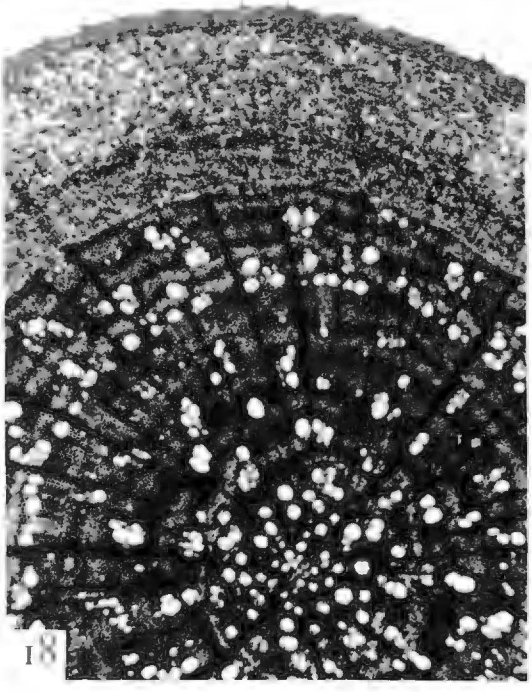

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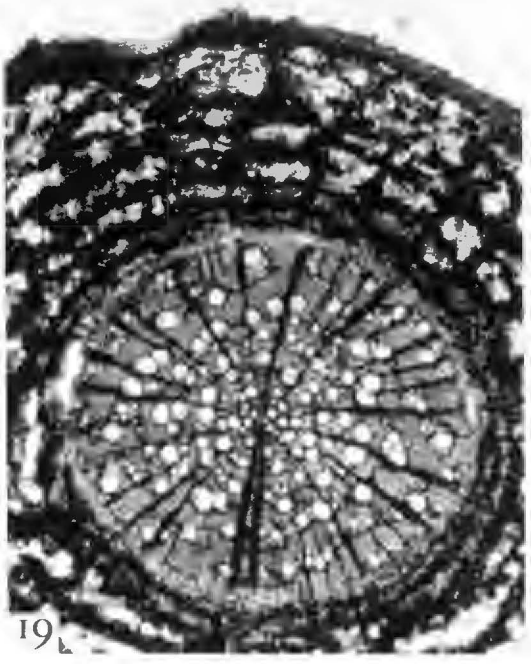

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found to contain 42.09 per cent more starch filled cells than those of Ulmus pumila. Similarly, stems of Ulmus americana had 16.21 per cent more starch granules per given cross sectional area than those of Ulmus pumila. Comparing root and stem sections of the same species, it is apparent that roots had the greatest accumulation of starch.

The use of polarized light was more effective when used to distinguish between the various tissue systems than it was for the study of starch concentration. Measurements of light transmission through the stained sections showed the greater accumulation of starch in the root portions of the seedlings. The greater differential staining, resulting in the lower amount of light transmission, substantiated the data obtained by quantitative evaluation.

Comparison of stem and root structure

All sections were cut to a uniform thickness of 35 microns. Cross sections of stems of the Siberian elm generally contained a greater amount of loose walled parenchymatous tissue associated with the cortical region than did the American elm. The structure, otherwise, was similar for both species. This same observation held true for root sections in which the cortex of the Siberian elm was composed of large, thin walled cells. Root sections of the American elm contained a number of smaller, more uniform cortical cells.

This fact suggests one explanation for the greater moisture content of both stem and root sections of the Siberian elm. The larger cell size might also be responsible for the relatively rapid loss of moisture from seedlings of Ulmus pumila.

Stems of the two species under investigation were sectioned after removal of the wax layer. A comparison of these sections containing lateral buds with those which had not been waxed showed no differences. If the growing point of the bud or the cortical tissues of the stem had been injured, there would have been evidences of cell rupture and attendant discoloration of these tissues. Therefore the decreased bud break associated with the waxing treatment could not be the result of injury to the buds caused either by high temperature or by infiltration of the wax.

SUMMARY AND CONCLUSIONS

Summary

For some time, nurserymen have been cognizant of the difficulty of holding seedlings of the Siberian elm, Ulmus pumila, during winter storage in a dormant condition. This problem has been aggravated by the emphasis that has been placed on the production of selected clones, which are being marketed as hybrids between this species and the American elm, Ulmus americana.

The purpose of this study was to establish the responses of the American and Siberian elms to known laboratory environments. After establishing morphological and physiological characteristics of the two species, it was the further purpose of this study to investigate the effects of root and stem packaging treatments in relation to storage and field performance.

After seedlings of uniform height and caliber had been selected for storage and field experiments, preliminary studies on the remaining samples were made to ascertain moisture content, rate of moisture loss, and anatomical studies. In order to study the effect of packaging treatments on storage and field performance, plants were packaged using combinations of three root treatments and four stem treatments. After treatment application, plants were placed

in refrigerated storage from March 20, until July 5, 1959. These were then field planted, and performance data were obtained on sprout development, growth, and overwintering.

Seedlings of Ulmus pumila had more original branches, greater numbers of buds per given stem area, higher respiratory activity, higher moisture content, more rapid water loss when stored at room temperature, and a smaller number of starch filled cells, in comparison to seedlings of Ulmus americana.

Final storage observations revealed bud break was similar to the mid-storage observations and that seedlings of Ulmus pumila had more total buds breaking dormancy than Ulmus americana. Bare root storage and stem waxing resulted in fewer buds breaking dormancy while the sphagnum root packs were responsible for the greatest root initial development. Moisture percentages of both the packing material and the plant sections were found to be relatively constant throughout the storage period. There was little variation in the starch content of stem and root tissues during the storage sequence.

Treatments that had the greatest amount of forced growth at final storage were those which were growing most poorly in the field. Treatments that remained dormant, or nearly so, in storage grew normally after planting. At the conclusion of the first growing season, seedlings of Ulmus

pumila had more new sprouts and greater linear development than seedlings of Ulmus americana. Seedlings in treatments which made use of the wax stem dip made more growth and were generally superior to seedlings included in the other treatment combinations. Although variation was observed between plants included in both the storage and field experiments, no differences were found between replications of experimental material.

Field performance was related to the maintenance of dormancy during the storage period and the prevention of desiccation. Seedlings of Ulmus pumila are more difficult to store under these circumstances than are seedlings of Ulmus americana.

Conclusions

1. Sections of Ulmus pumila maintained a higher percentage of moisture than comparable sections of Ulmus americana, while root sections were found to contain more water than stem portions.

2. Moisture loss was greatest through the cut ends of stem sections, while the greatest amount of water was lost through the epidermal region of the roots.

3. Ulmus pumila maintained fewer starch filled cells per cross sectional area and a higher percentage of loose walled parenchymatous tissue than comparable segments of

Ulmus americana. Root sections contained a higher starch content than stem sections.

4. Waxing markedly reduced moisture loss from sections stored at room temperature and was not detrimental to tissue systems when applied at 167°F.

5. Respiratory activity was found to be greater for root and stem sections of Ulmus pumila than Ulmus americana. Roots were found to respire at a higher rate than stem sections.

6. Sections stored in a packing material were found to have the highest respiratory activity. The lowest respiratory activity for roots resulted from roots stored without a packing material, while waxing resulted in a similar response for stems.

7. Sprouting in storage was generally confined to the distal region of the seedlings. Although Ulmus pumila had more total bud breaks than Ulmus americana, these were shorter in length and resulted in less total growth.

8. Stem waxed seedlings stored without root packaging were the most satisfactory from the standpoint of continued dormancy.

9. The higher moisture sphagnum packs favored adventitious root initial development, while only the polyethylene enclosure was found to have the least activity.

10. Seedlings which remained dormant in storage were

quick to establish after field planting. These plants had more growth during the summer than those which had sprouted in storage.

11. Stem treatments were found to have more influence upon field performance in terms of plant establishment, growth, and survival overwinter than root treatments.

12. The best individual treatment combination, as related to storage and field performance, was roots stored without a packing material in combination with stem waxing (Treatment 9). The poorest field response resulted from seedlings receiving no packing material on either the root or stem portions (Treatment 12).

13. Seedlings of Ulmus pumila were more difficult to store than those of Ulmus americana, as related to profusion of bud break in storage, although they produced more linear growth upon completion of the growing season.

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