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RESEARCH REPORT...
RESPONSE OF TROPICAL AND SUBTROPICAL WOODY PLANTS TO CHEMICAL TREATMENTS

Agricultural Research Service
U.S. DEPARTMENT OF AGRICULTURE
Under ARPA Order No. 424
Advanced Research Projects Agency
U.S. DEPARTMENT OF DEFENSE

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RESEARCH REPORT. . .
RESPONSE OF TROPICAL AND SUBTROPICAL WOODY PLANTS TO CHEMICAL TREATMENTS

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CONTENTS

ABSTRACT

The forests of Southeast Asia, Puerto Rico, and Texas show considerable differences in floristic composition, but the principle types have affinities from the standpoint of structure, life form, and environment. Among the forest types having affinities are the Evergreen Forest and Mangrove Woodland of Southeast Asia and Puerto Rico, Deciduous Forest of Southeast Asia and Texas, and the Thorn Forest of all three areas.

Paraquat was the most effective chemical tested for rapid defoliation of woody plants. In rain forests 20 to 30 lb. per acre are needed and in drier forests with significantly less biomass, 10 to 15 lb. per acre. Low temperature reduced the rapidity of leaf necrosis during the first 48 hr. after treatment, but the temperature effect was negligible after 96 hr. Photodecomposition of paraquat occurred readily.

Picloram was the most effective herbicide tested for long-term defoliation of woody plants. This was true whether picloram was applied to foliage or to the soil. Compared with phenoxy herbicides, picloram was more readily absorbed by leaves or roots, it was translocated more extensively and in greater quantity in the plant, it provided greater bud suppression, and was effective on a wider range of species. The latter point is of particular importance in forests having a high species diversity. Treatment with 3 gal. of picloram per acre (6 lb.) was as effective as 3 gal. of orange (24 lb.).

M-2993 (4 lb. of 2,4,5-T and 1 lb. picloram per gal.) was also as effective or more effective than orange on an equal volume basis.

Bromacil was the best herbicide tested for the control of grass species and for general soil sterilization.

Woody plants in areas having seasonal rainfall are seasonally susceptible to herbicides. The most susceptible period occurs when soil moisture has been adequate for rapid growth, but after terminal twig elongation has stopped. Woody plants growing in areas where rainfall is high, but uniformly distributed throughout the year, are probably less subject to seasonal susceptibility.

Secondary growth following defoliation occurs rapidly in wet tropical enviroments. Significant regrowth occurred 6 mo. after herbicidal treatment of foliage, and 12 mo. after application to the soil. Grasses, sedges, and vines are the first components of secondary growth and some woody seedlings appear soon thereafter.

Vertical and horizontal obscuration are linearly correlated with defoliation. Air-to-ground obscuration was greatly reduced by 50 percent or more defoliation, but the degree of obscuration was dependent on angle and direction of sight. Vertical obscuration was reduced from 85 percent where there was no defoliation to 40 percent where there was 100-percent defoliation. Horizontal obscuration was reduced by defoliation but was also dependent on stem density and basal area. The percentage of horizontal obscuration was reduced from about 55 where there was no defoliation to 25 where there was 100-percent defoliation.

The percentage of spray penetration through forest canopies was inversely related to canopy density. Other factors such as evaporation and drift being equal, the inverse relationship was linear through the entire range of 0- to 100-percent canopy density. In a dense, two-storied forest, about 80 percent was intercepted by the top story and an additional 15 percent by the middle story, leaving 5 percent for vegetation on the forest floor.

The research described in this report was conducted by personnel of the Agricultural Research Service, U.S. Department of Agriculture under contract with the Advanced Research Projects Agency, Department of Defense. This report is submitted in accordance with ARPA Order No. 424, Program Code No. 3860 dated January 30, 1963; Amendment No. 1, Program Code No. 4860 dated April 2, 1964; Amendment No. 2, Program Code No. 5860 (11) dated March 5, 1965; and Amendment No. 3, Program Code 6G10 (11) dated March 29, 1966.

ARPA Order No. 424 and its amendments directed the Agricultural Research Service to evaluate new herbicides or combinations of herbicides for killing tropical and subtropical vegetation, develop methods of evaluating herbicides on different woody species, determine the effects of environment on behavior and effectiveness of toxic herbicides, determine optimum dates and rates of application, relate the percentage of defoliation to horizontal and vertical obscuration, develop methods for improved application techniques that provide better distribution patterns, and obtain the botanical information needed so that correlations might be made between vegetation indigenous to Continental United States (CONUS), Puerto Rico, and Southeast Asia. The last objective has been satisfied by two U.S. Department of Agriculture Publications entitled, "Vegetation of Southeast Asia: Studies of Forest Types, 1963-65" (CR 49-65) December 1965, and "Forests of Southeast Asia, Puerto Rico and Texas" (CR 12-67), 1967. The remaining directives are included in this report.

This publication completes the reporting requirements of ARPA Order No. 424 and its amendments. However, a short supplementary report will be submitted after we have final data from the latest tests. Those data will be available in November 1967.

Trade names are used in this publication solely for the purpose of providing specific information. Mention of a trade name does not constitute a guarantee or a warranty of the product by U.S. Department of Agriculture or an endorsement by the Department over other products not mentioned.

Underscored figures in parentheses refer to Literature Cited at the end of respective chapters.

Crops Research Division

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The engineering research in Texas was done by L. F. Bouse; that in Puerto Rico by J. R. McCalmont and Mills H. Byrom.

Taxonomic investigations were made by Llewelyn Williams, principally in Southeast Asia, but also in Texas and Puerto Rico. Particular thanks are due to James A. Duke whose taxonomic work on the mature and seedling woody species of Puerto Rico was of invaluable help.

We are indebted to the administrators and many staff members of the Texas Agricultural Experiment Station, College Station, Tex., for providing us with space and facilities. Our task would have been much more difficult without their help and splendid cooperation. In like manner the Federal Experiment Station in Puerto Rico deserves thanks for providing space and facilities. In addition, their knowledge of the island and its inhabitants contributed much to the work in Puerto Rico.

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Naming all of the companies that contributed herbicides for experimental purposes would indeed make a long list. All companies that were approached willingly provided experimental samples of herbicides for experimental purposes. Their contributions are sincerely and gratefully acknowledged.

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RESEARCH REPORT . . .
RESPONSE OF TROPICAL AND SUBTROPICAL WOODY PLANTS TO CHEMICAL TREATMENTS

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SUMMARY

Despite the fact that many woody species have been introduced from one area of the world into another, the forested areas of Southeast Asia, Puerto Rico, and Texas show considerable differences in floristic composition. Introduced species are commonly found along roadsides and around habitations, but most have not been naturalized to the extent that they are commonly found in forested areas.

Aside from floristic composition, the forests of Southeast Asia, Puerto Rico, and Texas, at least the principle types, have definite affinities from the standpoint of structure, life form, and the environment in which they grow. The Evergreen Forest of Southeast Asia resembles the Luquillo National Forest of northeastern Puerto Rico. Precipitation is high and the constant high humidity and abundant soil moisture contribute to the development of a lush plant growth. Numerous short trees, slender vines, and stout lianes obstruct horizontal visibility. Heavy foliage in the contiguous crowns of the top story hamper vertical visibility.

Deciduous Forest in tropical regions such as in northern Thailand resembles the Mixed Deciduous Forests of temperate regions, especially when the branches are bare of leaves. Such trees as oaks and magnolia, important elements of Temperate Forests, are represented by a number of species in the Upland Montane Forest of Southeast Asia. The Mangrove Woodland of Puerto Rico bears a striking resemblance to that in Southeast Asia. Two of the species are congeneric. Thorn thickets are frequent in all tropical and subtropical regions. Many of the woody species are armed with short or long spines on branches or trunks. Several shrubs or small trees regarded as brush on rangeland in Texas have a pantropical distribution and are frequent in the Thorn Thicket of Puerto Rico and Southeast Asia.

Many herbicides were evaluated for their effectiveness in defoliating woody plants rapidly. Paraquat and diquat provided the most rapid defoliation of all the chemicals that were tested, and in most cases, paraquat gave slightly better results than did diquat. The rapidity of defoliation varied widely with the species. Those having small, succulent leaves were defoliated rapidly; those with large, leathery leaves slowly. In most cases, necrosis was apparent within a few days after treatment and within 1 week after treatment, considerable defoliation had occurred. The rate of paraquat needed to provide a high percentage of defoliation varied widely among species. In general, rates of 20 to 30 lb. per acre were required in Rain Forest, but 10 to 15 lb. were adequate in drier forests with significantly less biomass. Low temperature reduced the rapidity of leaf necrosis during the first 48 hr. after treatment with

paraquat, but the temperature effect was negligible after 96 hr. Laboratory studies showed that plant leaves must be exposed to direct light before a maximum effect from paraquat is obtained.

Picloram, with few exceptions, was the most effective herbicide tested for long term defoliation. Picloram was not equally phytotoxic to all woody species and the rate required for effective defoliation varied widely. As was the case with paraquat, there appeared to be a relationship between the amount of picloram needed for effective defoliation and the amount of rainfall that occurred in the area. Again, this may not have been directly related to the environment, but rather to the relative mass of vegetation.

The broad spectrum of woody species susceptible to picloram makes it an extremely important herbicide for woody plant control. The use of picloram is particularly appropriate for the defoliation of forest types characterized by high species diversity. Such forest types are frequently found in tropical environments. Picloram also provides greater suppression of lateral and basal dormant buds than do other herbicides. The combined advantages of effectiveness on many species and greater bud suppression make picloram the best single herbicide available for woody plant control. Our research experience with picloram indicates that gallon for gallon it equals or exceeds the control obtained with any other herbicide. This point is particularly significant because picloram contains only 2 lb. of active material per gallon whereas orange contains 8 pounds.

Equivalent volumes of picloram, M-2993, M-3140, and orange or purple caused approximately equivalent defoliation. Three gallons per acre was required in wet forests, but lesser amounts caused effective defoliation in drier forests with less vegetative biomass.

The relative amounts of picloram and phenoxy herbicides translocated within various plants were studied in plants growing in the greenhouse and in the field. All studies showed that picloram was translocated more readily than 2,4-D or 2,4,5-T. Greater mobility within plants is probably one reason that picloram exhibits more suppression of dormant buds than do the phenoxy herbicides. Furthermore, 2,4,5-T was not translocated from leaves until the leaves were fully expanded. This emphasizes the importance of delaying field applications of 2,4,5-T until after leaves have reached full size. Moisture stress reduced the translocation of 2,4,5-T to a much greater degree than picloram.

Woody plants can also be effectively controlled by making herbicidal applications to the soil. Vegetation control can be obtained for relatively long periods of time if enough herbicide is used and there is not too much rainfall. Some woody species will be killed by one herbicide but not with another. Complete woody plant control in areas having a high species diversity can only be achieved if enough herbicide is applied to overcome the effects of differential species susceptibility. The necessary rate varies with herbicides, but could be as low as 10 lb. per acre in dry areas, and as much as 27 lb. per acre or more in extremely wet areas.

The most effective herbicides applied at relatively low rates to the soil in dry areas were picloram, fenuron, bromacil, and prometone. In wet sites, picloram was unquestionably most effective. Dicamba and bromacil gave fair control in wet sites, but about three times as much herbicide was required for dicamba and bromacil as for picloram to give an equivalent degree of control. In general, 10 lb. per acre of picloram, fenuron, bromacil, and prometone will give effective woodly plant control in dry areas. In wet areas, 27 lb. per acre, or more, are required and picloram was the only herbicide proved to be effective.

Research indicated that picloram is mobile in the soil, but does not degrade rapidly. In heavy clay, picloram remained at phytotoxic levels for long periods of time. In sand, on the other hand, leaching soon carries the picloram to soil depths that roots do not usually penetrate.

Ultraviolet light decomposes picloram rapidly.

The degree of revegetation following application of a herbicide to either the foliage or to the soil depends primarily on the amount of rainfall that occurs in the treated area. Considerable regrowth occurs within 6 mo. after application to the foliage with high rates of orange. Both the rate and degree of regrowth are lower when equivalent volumes of picloram are applied. Application of 27 lb. per acre of picloram to the soil in a rain forest resulted in almost complete control of the woody vegetation. Within 1 yr. after treatment, however, the ground floor was completely covered with grasses and sedges, and woody seedlings were also becoming established. Two years after treatment, some of the new woody plants had reached a height of 8 to 10 ft. Vines were also prevalent.

Grasses and herbaceous weeds are almost always the first vegetation types to reinvade an area after treatment with herbicides. In dry areas, the grasses and weeds are of low stature, but they become increasingly taller as the amount of rainfall increases. Grasses reaching a height of 8 to 10 ft. are not uncommon in wet tropical areas. Thus, if defoliation is maintained in a wet evergreen forest, grasses, sedges, and vines will quickly become established on the forest floor. These do not offer as great an impediment to mobility as do trees, but horizontal obscuration would be virtually complete.

Horizontal and vertical obscuration are not improved greatly unless the percentage of defoliation exceeds 50 percent. When horizontal and vertical obscuration are predominant factors to be considered in assessing herbicidal effectiveness, any chemical that provides less than 50-percent defoliation should not be used. In like manner, when the degree of refoliation has been adequate to reduce the general percentage of defoliation to 50 percent, retreatment will be necessary.

Aerial applications of different types of spray materials showed that water was distributed more uniformly than were invert emulsions or particulated sprays. This suggests that sprays of low viscosity have better distributional patterns thatn those of high viscosity. However, differences in percentage penetration through forest canopies due to type of spray material were small. The percentage of drop penetration decreased rapidly between droplet densities of 0 to 100 per square in., but remained stable thereafter. The percentage of spray penetration through forest canopies was inversely related to canopy density. Other factors, such as evaporation and drift being equal the inverse relationship was linear through the entire range of 0 to 100 percent canopy density.

INTRODUCTION

Defoliation of vegetation to reduce obscuration has long been recognized as having a tactical military advantage. Any process that reduces the amount of obscuring vegetation will permit easier detection of personnel and equipment. The possibility of ambush is reduced and the movement of enemy equipment and personnel can be more easily observed.

The importance of obscuring vegetation is particularly important in tropical areas. Tree density is high and vines, epiphytes, buttressed roots, and fallen trees add greatly to the degree of obscuration. Second-growth forests, which are commonly characterized by a profusion of vegetation often divided into several canopy layers, are particularly notorious for hindering both movement and sight. Obscuration is important not only in horizontal plane but also in oblique and vertical planes. The ability of a man on the ground to spot approaching aircraft, or, conversely, the ability of an aerial observer to see personnel and equipment on the ground is highly important.

Some forested areas in Vietnam were sprayed with herbicides in the early 1960's in an effort to reduce the amount of obscuration by vegetation. The results were particularly good on mangrove in coastal areas and along canals. Results on evergreen rain forests and upland semideciduous forests left much to be desired. Consequently, a team of military and civilian experts reviewed the operational spray program and made recommendations for improvement. Since there was a dearth of information available about the response of tropical woody plants to herbicides, a research program was recommended that would answer some of the critical problems involving the defoliation of tropical forests. That recommendation was accepted and the Advanced Research Project Agency of the U.S. Department of Defense entered into discussions with the Agricultural Research Service of the U.S. Department of Agriculture to determine the nature and extent of an effective research program. The Agricultural Research Service proposed a research program combining the scientific disciplines of weed science, taxonomy, and agricultural engineering. Research locations were to include Southeast Asia, Puerto Rico, and Texas. Concurrently, the Advanced Research Projects Agency contracted with the U.S. Army Biological Center to conduct research on the defoliation and control of tropical forests in Thailand.

ARPA Order No. 424 was issued January 30, 1963. The work involved in staffing for the project was begun almost immediately. Botanical investigations were assigned to Llewelyn Williams. He studied the vegetation of Southeast Asia and compared it with the vegetation of Puerto Rico and of Texas. James A. Duke joined the botanical staff later in the year and concentrated his efforts on the vegetation of Puerto Rico.

Two weed scientists were already stationed at College Station, Tex. Although they were not assigned to the ARPA project on a full-time basis, they initiated the first work that was done on the project in Texas and contributed substantially to the information that was ultimately developed. These two scientists, H. L. Morton and R. E. Meyer, were joined by M. G. Merkle, R. W. Bovey, and F. S. Davis who worked full-time on the ARPA project. L. F. Bouse, an agricultural engineer, transferred from Stillwater, Okla., to join the ARPA group at College Station.

C. C. Dowler and F. H. Tschirley arrived in Puerto Rico in April and June 1963, respectively, to begin work on the defoliation program. In October 1963, they were joined by J. R. McCalmont, an agricultural engineer, to conduct the work on spray penetration through tropical forest canopies. Mr. McCalmont retired from Government service in October 1965 and was replaced by Mills H. Byrom who continued the work that had been started.

ARPA Order No. 424 was established for a 2-year period. The objectives of the work in College Station, Tex., were to: "Discover and evaluate new herbicides and principles for killing trees, brush and other vegetation; develop methods of evaluating herbicides on different species of woody vegetation; develop methods and principles for improved application techniques; and determine effects of environment on behavior and effectiveness of promising herbicides." The objectives of the research in Puerto Rico were to: "Conduct advanced evaluation of promising herbicides for killing tropical and subtropical vegetation; and determine optimum times and rates of application, distribution patterns, formulations and mixtures for most effective use of herbicides." The objectives of the taxonomic investigation were to: "Obtain sufficient botanical information so that correlations can be made between vegetation indigenous to CONUS and Puerto Rico, and Southeast Asia."

ARPA Order No. 424 was extended for an additional year by Amendment No. 2 dated March 5, 1965. Additional objectives of the research were to: (1) Emphasize effects of environment on behavior and effectiveness of herbicides and persistence of control including residues in soils and plants, (2) study secondary succession of vegetation following different herbicidal treatments as related to "visibility," (3) correlate the results of defoliation in Texas and Puerto Rico, (4) investigate methods for improving absorption, translocation, and activity of herbicides and defoliants, and (5) compare the penetration of sprays through a forest canopy that is obtained from a cableway system with that obtained from aircraft.

A second extension was granted by Amendment No. 3, dated March 29, 1966. During the final year of the project, increased emphasis was given to the effects of environment on herbicidal effectiveness, the composition and frequency of successional species following herbicideal treatment, the effect of defoliation and subsequent regeneration on the degree of obscuration, and herbicidal residues in both plants and soils.

The interrelation of data from the fields of taxonomy, ecology, weed science, and engineering have been extremely valuable during the course of this project. It is axiomatic that the breadth of a study determines the extent to which data developed from that study can be extrapolated. For example, a great deal of research had been done on the control and defoliation of woody plants in temperate zones. Information was available regarding which herbicides were most effective, what rates should be used, and when treatments should be made. But no one could extrapolate that information to a tropical evergreen forest with any degree of assurance. In like manner, penetration of a spray solution through a forest canopy would be expected to be different for a desert shrub formation, a coniferous forest, a temperate deciduous forest, and a tropical evergreen forest. Once the effective herbicides, the penetration of spray solutions, and the taxonomic affinities of several diverse vegetative types are known, extrapolation of that information to entirely new areas can be made with much more assurance. Thus, the correlated efforts of taxonomists, engineers, and weed scientists in the ARPA project has provided information that can be applied with reasonable assurance on a worldwide basis, rather than being restricted to the area of investigation.

CHAPTER 1

FORESTS OF SOUTHEAST ASIA, PUERTO RICO, AND TEXAS THEIR AFFINITIES AND CONTRASTS

Southeast Asia, Puerto Rico, and Texas--three geographically distinct and distantly separated regions--are rich in plant life. A latitudinal range from equatorial to temperate and an altitudinal range from sea level to high mountains, result in an extremely variable climate, soil, and vegetation. The forests of the three areas exhibit considerable variation, each with a complex and distinctive flora. In addition to climatic and edaphic variables, the vegetation has also been influenced by felling, burning, grazing, and other agencies.

Southeast Asia encompasses the countries of Cambodia, Laos, Thailand, and North and South Vietnam, and has a total area of 505,000 sq. mi. Thus, Southeast Asia is slightly less than twice the area of Texas (262,120 sq.mi.), and about 148 times the size of Puerto Rico (3,420 sq. mi.). The five countries of Southeast Asia may be considered as a unit because of similar topography, climate, soil types, and vegetation. The general physiography of the entire Indochina Peninsula is that of great plains, plateaus, mountain ranges, with peaks upwards of 6,000 ft., and several large rivers flowing in a general southerly or southeasterly direction, with deltaic estuaries covered with Mangrove woodland. Except on the summit of mountain ranges, temperatures range from 70° to more than 100° F., and frost is known only on the highest peaks. Annual rainfall varies from about 40 to 150 in., and in limited zones up to more than 200 in.

Puerto Rico, like Southeast Asia, is situated well within the tropical belt, with a range of precipitation similar to that of Southeast Asia. Three physiographic zones are generally recognized: (1) A central mountain core of volcanic origin, (2) an elevated area of coral limestone surrounding the mountain ranges, and (3) the northern and southern coastal plains. The island is well drained by about 1,300 streams and small rivers.

Major physiographic zones in Texas are: (1) Gulf prairies, moderately level plains, and high plains, (2) rolling or irregular plains, such as those of the South Texas hill country and East timberlands, and (3) mountains and basins of the Trans-Pecos, with the highest peak, Guadalupe, rising to 8,730 ft. Many streams dissect the State, flowing irregularly from the northeast to the Gulf Coast. The climate is subtropical to temperate, with frost periods during the winter months in most of the State.

It is estimated that there are more than 10,000 species of plants in Southeast Asia. Approximately 1,500 are woody, ranging from shrubs and small trees in thorn thickets to tall trees up to 90 or 100 ft. in height in the dense humid evergreen forests. Many plants of tropical American origin have been introduced into Southeast Asia, particularly those esteemed for their edible fruits, seeds as a source of food, or as ornamentals. Likewise, a large number of economic or ornamental plants of Asiatic origin have become naturalized in Puerto Rico and elsewhere in tropical America. Many of them grow spontaneously, but seldom develop in the forests, except in clearings or around abodes.

Of the 1,577 species of plants, indigenous and introduced, recorded in Puerto Rico, 500 are small to large trees. The forests contain a number of useful timbers, long esteemed for construction and other purposes.

Because of its large area and extreme variations in environmental conditions, Texas has a rich flora, with about 4,600 species of vascular plants. Many of these are represented, either by genus or species, in Puerto Rico, Southeast Asia, and other tropical areas. Grasses are exceedingly well represented in the State by about 112 genera and 570 species. In fact, grasses are more abundant, in terms of species, than in Southeast Asia or Puerto Rico. Many trees growing in other forest regions of Continental United States have developed, over the centuries, into well-established Texas varieties, because of their resistance to high temperature, drought, and ability to adapt to different types of soils. There are approximately 800 species of shrubs and trees in Texas, growing in forests covering approximately 26.5 million acres. These do not include mesquite, huisache, retama, and other species of brush considered as rangeland weeds. Several of these pest plants are found in Puerto Rico and Southeast Asia.

Because of great differences in the floristic composition of tropical, subtropical, and temperate forests, one of the most practical methods that can be applied to establish their affinities and dissimilarities is to consider primarily the structure or physiognomy, and life-forms of the principal types. This information is supplemented by a study of their floristics, data on annual and seasonal rainfall, soil conditions, and topography of the environment.

Most of the Korat Plateau, in northeast Thailand, has a rainfall of less than 40 in. annually, often intensified by drought. Consequently, much of the vegetation covering the plateau is composed of Thorn Thicket, Dry Dipterocarp Forest, Savanna, and Bamboo Brakes, typical of subarid to arid areas. At the other extreme, in the southern section of the Thai peninsula, where the annual rainfall of 80 to 150 in. is well distributed throughout the year, a tall Evergreen Rain Forest prevails. A similar pattern is obtained in Puerto Rico, with scrub thicket in the arid area around Guanica in the southwest, and dense Rain Forest in the high rainfall zone of the Luquillo National Forest in the northeast. In the eastern section of Texas, which has a rich and varied flora, annual rainfall ranges from 35 to about 50 in.

The forests of Southeast Asia, Puerto Rico, and to a large extent in Texas, have suffered severely over the centuries from human disturbance through felling of trees for construction timbers, fuelwood and charcoal, or to clear land for agricultural use. Considerable changes in the vegetation have been caused also by fires, either spontaneously or deliberately set, grazing by domesticated animals and wildlife, and attack by insect pests. Such direct or indirect disturbance has had a profound effect on the distribution and composition of the primary vegetation. In some of the more densely populated areas of both hemispheres, the natural vegetation has been so completely replaced by secondary plant communities that it is now difficult to reconstruct with certainty the original primary plant cover. In Puerto Rico much of the forest land area has been cleared for agricultural use and the remainder is almost entirely secondary forest. Only about 1 percent of the total area of the island consists of stands of primary forest. In Southeast Asia, also, the forests have been devastated for centuries. Only in the mountainous, less accessible regions are there extensive, undisturbed stands of pines and hardwoods of commercial value.

The three regions contain a broad range of forest formations ranging from tropical to temperate, with distinctive structural characters and extremely variable floristic composition. Nevertheless, certain plant formations in these widely separated areas exhibit certain definite affinities. For example, the Post Oak Savanna of East Texas is reminiscent of savanna in eastern and northeastern Thailand, or the dry Dipterocarp Savanna in the north. Open savanna in the Kra Isthmus of central peninsular and eastern Thailand resembles the open plains of eastern Texas. In all instances the grass cover is the dominant factor.

While the forest components of Texas, as in other temperate regions, may be broadly classed as conifers or softwoods, and broad-leaved or hardwoods, in Southeast Asia hardwood species predominate almost throughout the entire Indochina Peninsula. One group characteristic of Southeast Asia, and where it attains its best development, is the wood-oil family (Dipterocarpaceae). These trees, many of which furnish commercial timbers, do not occur in the western Hemisphere.

Conifers figure prominently in the vegetation of East Texas. They are represented by five genera: (1) Cypress (Cupressus), (2) juniper (Juniperus), (3) Douglas fir (Pseudotsuga), (4) bald and Montezuma cypress (Taxodium), and (5) particularly pines (Pinus). In Puerto Rico the only indigenous Conifer is Podocarpus coriaceus of the Yew family (Taxaceae). This genus is represented in Southeast Asia by four species. Several Conifers of ornamental value, including species of Araucaria, Cupressus, Chamaecyparis, Cryptomeria, Juniperus, Pinus, and Taxus, have been introduced into Puerto Rico from Asia and other tropical regions.

There are several genera of Conifers in Southeast Asia. Pines are especially well represented from the standpoint of distribution. Of these, the most widespread are the two-needled Pinus merkusii and the three-needled P. khasya. The latter forms extensive stands in northern Thailand, central Vietnam, and Laos. Other Conifers found in the central part of Vietnam and adjoining areas are species of Chamaecyparis, Cunninghamia, Keteleeria, Taxus, and Thujopsis. Some of these are abundant as far north as the border between North Vietnam and southern China, and beyond.

Tropical Rain Forest occurs in areas with high rainfall, in excess of 100 in., evenly distributed throughout most of the year, and with high soil and atmospheric moisture. The distinctive characters of this primary forest are the luxuriance of the vegetation, the preponderance of woody plants, and trees of tall stature, up to 50 ft., and some scattered emergent trees even reach 150 ft. The floristics of Tropical and Temperate Rain Forests, of course, are entirely different. Also, the number of species growing in a Tropical Rain Forest is far greater than is generally found in a Temperate Rain Forest. In a Temperate Rain Forest one or a few tree species may dominate, whereas in the Tropical Rain Forest there may be up to 100 or more species within an area of 1 acre. Tropical Rain Forest, identical in structure, occurs on the north slopes of the Luquillo National Forest in northwestern Puerto Rico, in southern peninsular and southeastern Thailand, on the Cardamom mountains of Cambodia, and in isolated parts of Vietnam. There are several areas in North America where a Temperate Rain Forest is found. One of the best analogues in Continental United States is the tall forest covering the western slopes of the Olympic Peninsula in Washington State.

Oaks constitute a major element of the woody vegetation of Texas, being represented by about 35 species, in addition to varieties. In Puerto Rico, however, oaks are insignificant, although several Asiatic species have been introduced. In Southeast Asia, several oak species, usually mixed with other hardwoods and Conifers, are frequent at medium and higher altitudes in the Montane Forest. They are particularly abundant in the central and northern parts of Southeast Asia. Species of oak are also found occasionally in the Moist Evergreen Forest, as in southern peninsular Thailand.

Vegetation in swamps or marshlands is a characteristic feature of the landscape in Southeast Asia, Puerto Rico, and Texas, as in other tropical and temperate regions. In tropical and subtropical areas such vegetation shows a gradation from the Mangrove Forest in saline water in deltas and around estuaries, to a distinctive type of vegetation in brackish water, and finally that thriving in freshwater swamps. In all areas, plants that flourish in saline and freshwater swamps are entirely different from the surrounding vegetation growing on dry land.

Mangrove Woodland, controlled by edaphic factors, forms the most homologous type of forest, from the standpoint of its structure, occurring in Southeast Asia and Puerto Rico. Although differences exist in the species composition, Rhizophora and Avicennia are represented both in Puerto Rico and Southeast Asia. Wherever it occurs, the physiognomy of this forest is similar, with contiguous crowns, dense foliage of various shades of green, and a flat canopy generally of uniform height. Stands of mangrove occur along the north and south coasts of Puerto Rico. These are generally lower in stature than the more extensive Mangrove Forests in Southeast Asia.

Mangrove does not occur in Texas, but its counterpart is the Cypress-Tupelo Swamp found in sections of the lower Mississippi delta. This swamp lies under water of fluctuating level except during periods of prolonged drought. In this environment cypress and tupelo appear to be the only trees able to tolerate constant flooding. Proceeding inland from the muck soil of cypress swamp, with its high content of organic matter and silt, there is a gradual decrease in water level as the land slowly rises, until a point is reached where the surface becomes firm and favorable for dryland species. The same pattern appears in mangrove belts.

Within the Rain Forest belt, differences in the length and severity of the seasonal dry period are expressed in variations in the floristic composition and structure of the vegetation. An example of this is the so-called Evergreen Seasonal Forest, with 4 to 6 mo. of little or no rain. Many of the trees are deciduous, and others are facultatively deciduous, that is to say the degree of leaf-shedding depends upon the length and severity of the dry period. Such a forest covers large areas in Southeast Asia and resembles the Rain Forest floristically and in its three-storied structure. A similar forest type is widely distributed in the Caribbean area and in mainland tropical America.

Another characteristic feature of the vegetation in Puerto Rico and Southeast Asia, as in all tropical and temperate regions, is the contrast between lowland and mountain flora. As we ascend mountain slopes the composition and structure of the vegetation undergoes a gradual change. In the lowland Hill Evergreen Forest of Khao Yai, in central Thailand, species of rattan (Calamus), fig (Ficus), dipterocarps (Dipterocarpus), and palms (Livistona, Caryota, Arenga) are common. In the Montane or Mid-mountain Forest, the most frequent forest trees are species of oak (Quercus), chestnut (Castanopsis), and a conifer (Podocarpus). On the flat summit other trees become dominant, such as species of Schima and another conifer, Dacrydium. Unlike the three-storied Rain Forest, Montane Forest has two, poorly defined strata. Most of the trees are slender with fairly small crowns, and form rather closed stands. On the mountains of northern Thailand, the oak-chestnut association is gradually supplanted by stands of the three-needled pine (Pinus khasya). In Puerto Rico Montane Forest, on the slopes of Luquillo Mountain range, the "colorado" type is represented in which Cyrilla racemiflora is dominant. The canopy is fairly uniform and does not exceed 45 to 50 ft. in height. All the trees are evergreen, and the leaves are typically thick and leathery. The ground is generally covered by leaves, and in some sites by a thick organic surface layer. Sphagnum moss abounds in moist sites.

Other forest types of similar structure, occurring in Puerto Rico and Southeast Asia, are the Elfin Woodland and Mossy Forest. In Puerto Rico, Elfin woodland grows on the upper slopes of Luquillo Mountain above the Montane belt. Because of constant clouds passing over the range, humidity is high. Strong gusts of wind blow constantly, so that the crowns of the low trees appear as if they had been sheared. In association with this formation, but on the leeward side, Mossy Forest appears. It is so named because of the abundance of mosses hanging from the trunks and branches. The soil is moist and boglike. Similar formations occur on the summit of Inthanon Mountain in northern Thailand and in limited upland sites in Khao Yai National forest in the central region.

Many species of bamboos occur throughout Southeast Asia in all types of soils and under a variety of climatic conditions. They are used for a multitude of purposes, such as for furniture, walls and partitions of houses, shade, windbreak, and water conduits to irrigate rice fields. The tender shoots of many bamboo species are edible. Wherever a clearing is made in a forest, or when tilled land is abandoned, certain species of bamboos are among the first plants to develop in successional growth. Puerto Rico has only a limited number of native bamboos, but several species have been introduced from Asia and other tropical regions. Some of these, particularly Bambusa vulgaris and B. tulda, have become firmly established and are widely distributed throughout the island along highways, banks of streams, and spreading into pastures and sugar-cane fields. Only one species of bamboo, the giant cane (Arundinaria gigantea), is represented in Texas, usually growing in moist sites.

In terms of species, palms are not as well represented in Puerto Rico as in Southeast Asia. Nevertheless, the sierra or mountain cabbage palm (Prestoea montana) is widely distributed in the island, especially in humid areas at middle and upper elevations. It is a frequent component of the understory in the Rain Forest of Luquillo, especially where there are openings caused by falling trees. It becomes more abundant, at times forming large breaks, at higher elevations and extends up to the Elfin Woodland on the summit. In the Commonwealth Forest of Toro Negro, in the central part of the island, pure breaks of this palm cover the upper slopes, and constitute the dominant element in that humid area. Nowhere in Thailand are there palm breaks comparable in extent to those of the sierra palm in Puerto Rico. Two of the most frequent species in Southeast Asia are Borassus flabellifor, usually growing individually or in open stands in rice fields, and the areca or betel-nut palm (Areca catechu), frequently propagated around hamlets, mostly in humid areas. Other frequent palms in Thailand are species of Corypha and Livistona, and Cocos, which is frequently propagated.

Savannas are much more widespread in tropical America, especially in central and northern South America, than in Southeast Asia. Savannas may be broadly classed as grassy or wooded. Shrubs and small- or medium-sized trees are seldom absent in any savanna. In both types the dominant factor is the grass cover. Typical examples of savannas in tropical America are the great llanos of Venezuela; the campo firme and castianga of Brazil; the pampas of Argentina; and the oak ridge and pine ridge of British Honduras. Savannas are small and not significant in Puerto Rico. The so-called Acacia-Prosopis savanna of southwestern Puerto Rico belongs more properly to Thorn Woodland, because the herbaceous ground layer is not considered dominant. Stretches of wooded savanna are found in the eastern, northeastern, and northern sections of Thailand, while rolling or flat, open savanna occurs in the Kra Isthmus in the Peninsula. Because of the open nature of savanna in all tropical areas, visibility, both horizontal and vertical, is not a problem.

Thorn thickets are also more frequent in the Caribbean and mainland tropical America than in Southeast Asia. This formation is particularly abundant in Venezuela along the northeast coast, on the northern edge of the llanos, and in the Guajíra peninsula to the west. The caatingas of northeastern Brazil also contain some Thorn Woodland and Cactus scrub.

In Puerto Rico thorn thicket occurs on nonsaline flats and coves between Ponce and Guánica and along the southwest coast. Cactus scrub occurs on the slopes. Several characteristic trees in these thickets are found in Puerto Rico and Southeast Asia. These include Acacia farnesiana, Parkinsonia aculeata, Leucaena leucocephala, Prosopis juliflora, and the pantropical Lantana camara.

Thorn thicket is well developed in the drier sections of Thailand, particularly in the upper Peninsula and on the Korat Plateau, in the Northeast. As in Puerto Rico and elsewhere in tropical America, annual rainfall in these areas is usually less than 40 in. Many of the shrubs and small trees represented in this formation are armed with short to long sharp spines. These include species of Bombax, Randia, Feroniella, Croton, Spondias, Zizyphus, and Vitex, in addition to the pantropical Acacia farnesiana. Often associated with these are the armed bamboo (Bambusa arundianacea) and a species of pricklypear (Opuntia).

The brush vegetation on rangeland in Texas is considered analogous to thorn thicket of tropical regions. Several genera, and even species, that occur in Texas, are also found in Puerto Rico and Southeast Asia. These include mesquite, huisache, and other species of Acacia, retama, and Macartney rose.

In tropical America as in Southeast Asia the pattern of development of secondary growth is essentially the same. The first stage of successional growth that develops following disturbance of dense, humid forest, whether in tropical America or Southeast Asia, is usually dominated by grasses and weeds. These are generally short-lived, of less than 1 yr. As a rule, plants that develop in the initial stage of secondary growth are entirely different from those that grow in the primary forest. The next phase may be dominated by shrubs, followed by trees of quick growth. Or the succession may lead almost directly from the herbaceous stage to tree dominance. The secondary forest is usually composed of fast-growing trees with soft wood, and their seeds are wind- or animal-dispersed.

The tropical Rain Forest is a prime example of a plant community in which rainfall, soil, and vegetation are the principle factors that contribute to the maintenance of a complex equilibrium. When one of the components of the primary forest is partially or completely destroyed, the other factors are altered and a new type of plant cover appears that is adapted to the modified environment.

The successional growth in the Rain Forest of tropical America is similar in structure to that of secondary Rain Forest in Southeast Asia, although it is quite different, of course, in floristic composition. The ubiquitous grass (Imperata cylindrica) is widely distributed in the Old World tropics and readily develops in forest clearings. This weed does not occur in tropical America except in Chile, but I. brasiliensis and other grasses are analogous. Intertwining sedges of the genus Scleria, with sharp-edged leaves, often form an almost impenetrable tangle in secondary forests of tropical America.

In Puerto Rico, as elsewhere in tropical America, perhaps the two most frequent trees in secondary forests are yagrumo hembra and yagrumo macho. Both propagate naturally and their growth is rapid.

In Thailand two weeds that develop most abundantly in abandoned land and in forest clearings are Eupatorium ordoratum, introduced from this Hemisphere, and the ubiquitous grass (Imperata cylindrica). Both plants are light loving and cannot thrive under shrubs and trees. Later the ground is colonized by shrubs. The shrub stage is followed by the development of a secondary forest in which trees of the genera Bombax, Dillenia, Vitex, and Grewia appear, and in humid sites species of wild banana (Musa) may appear. In many areas in Thailand, as in the other Mekong basin countries, woods, grasses, and shrubs are gradually dominated by bamboos, particularly species of Bambusa and Thyrsostachys, which may even suppress the development of trees. This is particularly noticeable in mixed deciduous forest, such as cutover stands of teak, as well as in humid Evergreen Forest.

To summarize, although the forests of Southeast Asia, Puerto Rico, and Texas show considerable differences in their floristic composition, the principal types exhibit definite affinities from the standpoint of structure, life form, and environmental factors.

The Rain Forest of Southeast Asia resembles the humid Evergreen Forest in the Luquillo National Forest of northeastern Puerto Rico. Precipitation is high, and the constant high humidity and abundant soil moisture contribute to the development of a lush plant growth. In the two areas, the respective forests have three stories: (1) An undergrowth of shrubs, young palms, and lianes; (2) a ground layer of herbaceous plants, ferns; and (3) seedlings of woody species. Dominant trees in the canopy generally have long, straight, cylindrical boles, and some are provided with short or high, thick or thin buttresses. Slender vines and stout lianes are frequent, and the contiguous crowns, often with heavy foliage, hamper vertical visibility both upward and downward.

Seasonal or deciduous forest in tropical regions, such as that of northern Thailand, and where teak is dominant, resembles the mixed Deciduous Forest of temperate regions, especially when the trees are leafless.

Such trees as oaks, pines, and magnolia, important elements of temperate forests, are represented by a number of species in the upland Montane Forests of Southeast Asia.

Mangrove Woodlands, frequent in tropical and subtropical regions, are similar in general structure wherever they occur. Some Mangrove trees have special adaptations such as prop roots, and pneumatophores, enabling them to survive continuous immersion in water. Many woody species growing in thorn thickets, and frequent in all tropical and subtropical regions, are armed with short or long, sharp spines on the branches and trunks or both. Several shrubs or small trees, regarded as brush on rangeland in Texas, have a pantropical distribution, and are frequent in thorn thickets in Puerto Rico and Southeast Asia.

Saline and freshwater swamps or marshlands, with distinctive vegetation, occur in the three regions.

Examples of vegetation similarity are shown in the paired photos that follow.

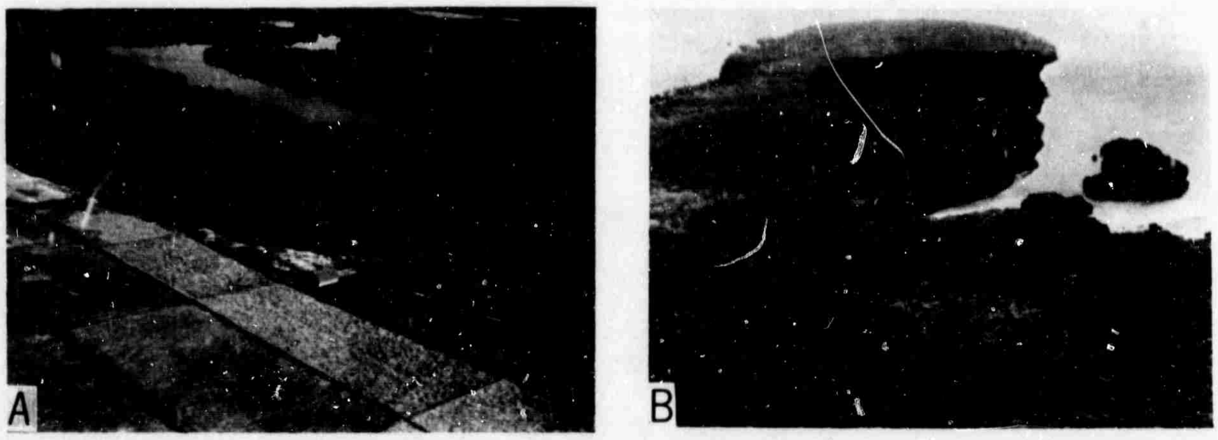

Figure 1.1.--Mangrove woodland: (A) Southeast Thailand; (B) northeast Puerto Rico.

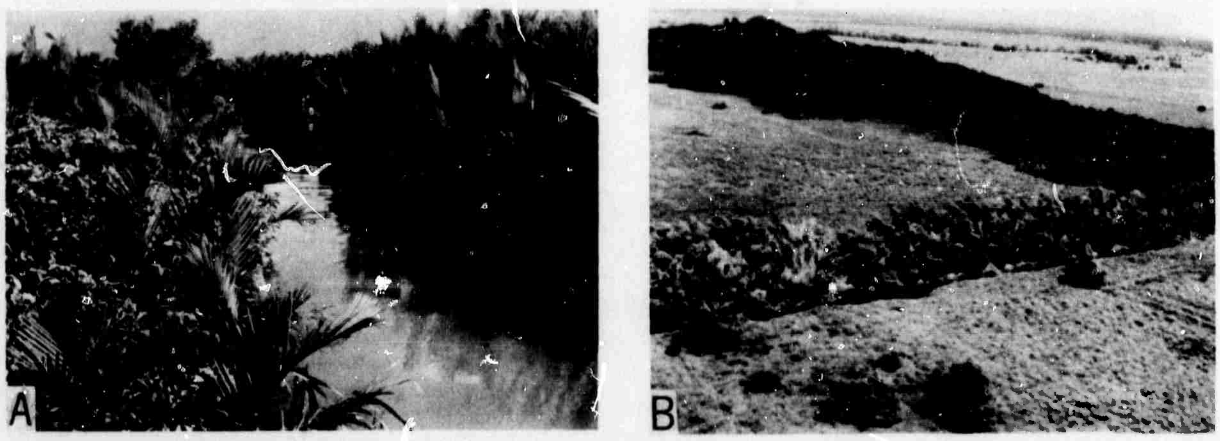

Figure 1.2.--(A) Nipa palm swamp, estuary of Chao Phraya River, Thailand; (B) Riparian forest with common bamboo (*Bambusa vulgaris*) dominant, northeastern Puerto Rico.

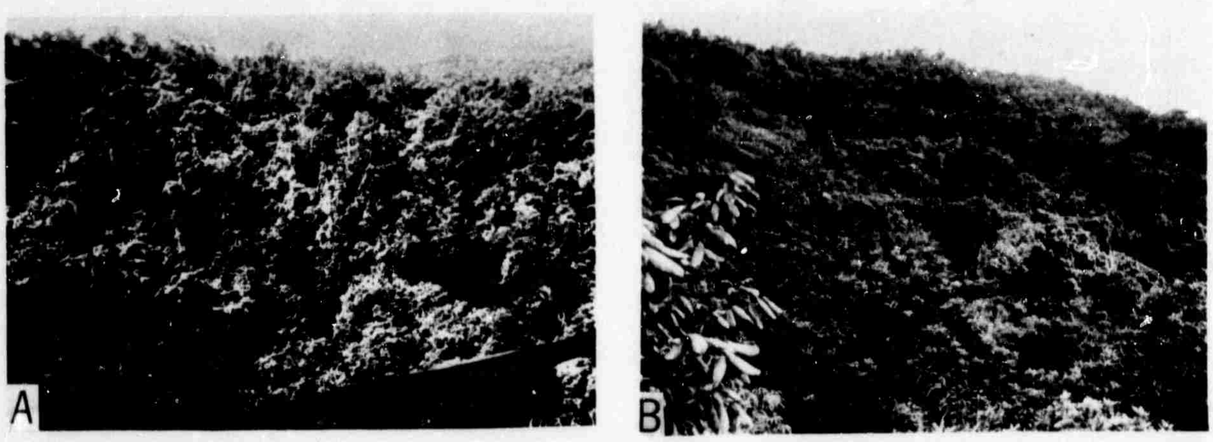

Figure 1.3.--Moist Evergreen Forests: (A) Khao Yai National Forest, central Thailand; (B) Luquillo National Forest, Puerto Rico.

Figure 1.4.--(A) Palmyra palm (Borassus flabellifer) in upper peninsular Thailand; (B) palma de sierra in Toro Negro Commonwealth Forest, Central Puerto Rico

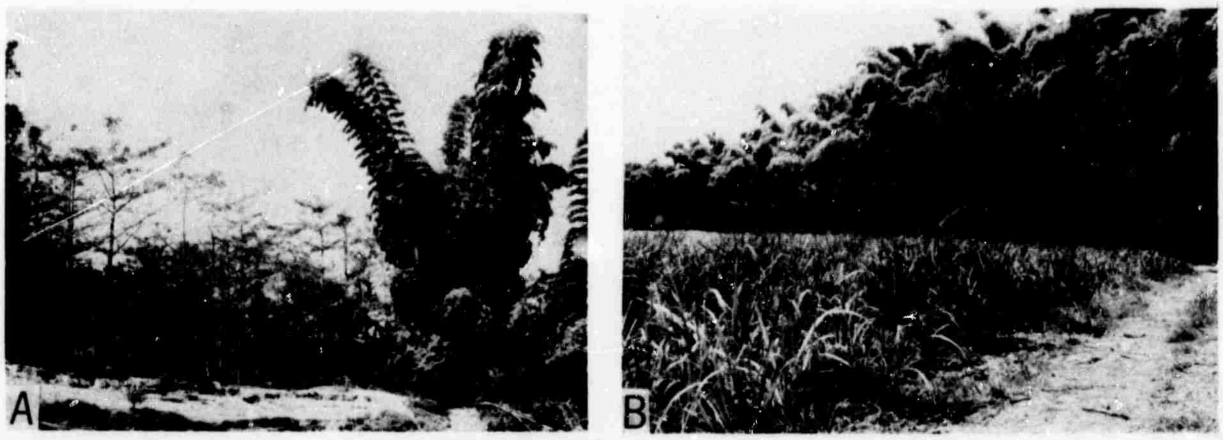

Figure 1.5.--(A) Secondary growth of Bambusa arundinacea in a mixed hardwood deciduous forest, northeast Thailand; (B) Bambusa vulgaris encroaching on sugar cane fields, western Puerto Rico.

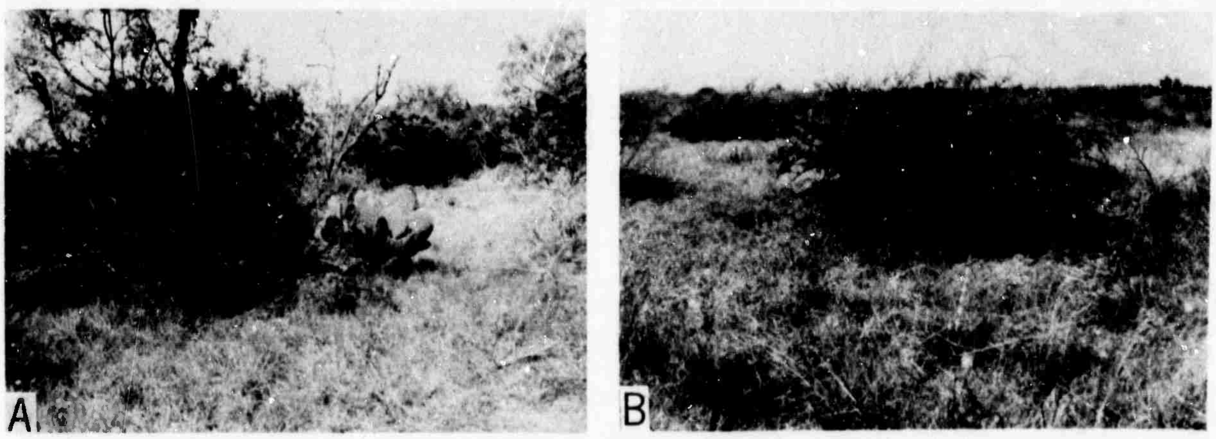

Figure 1.6.--Thorn brush: (A) Upper peninsular Thailand; (B) Macartney rose in southeast Texas.

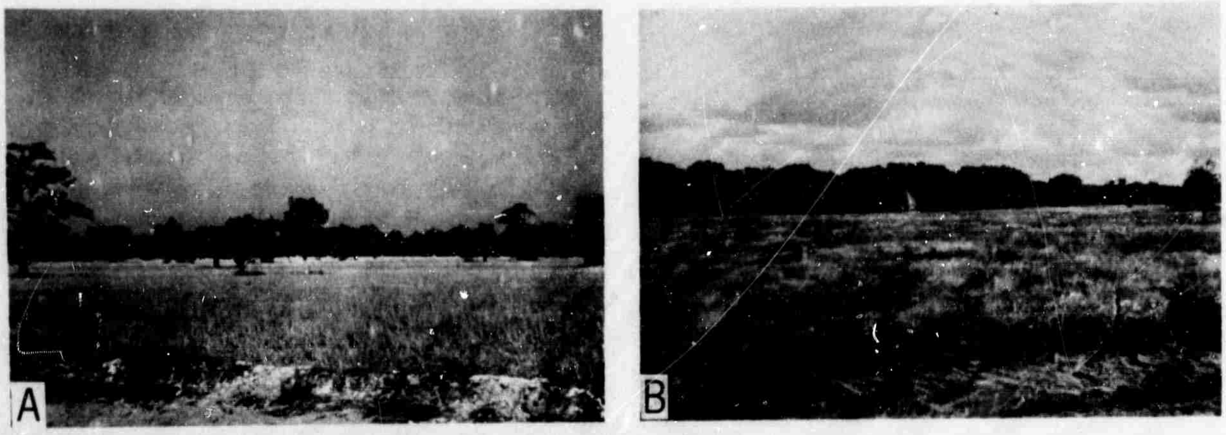

Figure 1.7.—Wooded savanna: (A) Nakhon Phanon, northeast Thailand; (B) post oak east of College Station, Tex.

CHAPTER 2

LABORATORY-GREENHOUSE RESEARCH ITS RELATION TO FIELD STUDIES

Research is concerned with controlling variables that may influence the end result. The control of variables in research on biological systems in the field is extremely complex. In addition to environmental variables, such as temperature, humidity, precipitation, soil type, and solar radiation, the inherent genetic variation of the biological test organism itself is a confounding factor. Thus, the conduct of research in a laboratory or greenhouse, where environmental variables and some of the biological variables can be controlled, is not only desirable, but necessary.

One of the most difficult aspects of research on woody plant control is the development of principles that will predict future results accurately. No one approach is consistently more effective than others. In our research we used the approach that we felt would answer a given question most efficiently and effectively. The use of research in laboratory and greenhouse facilities increases efficiency in many situations by reducing the number of variables.

The combination of laboratory, greenhouse, and field research in this project has been fruitful. More useable information has been obtained by using the multiple approach than would otherwise have been possible.

Biological Activity of Herbicides

Several herbicides, which were subsequently used effectively in field trials, were evaluated on greenhouse-grown plants of several woody plant species.

Ten phenoxy compounds were evaluated on whitebrush seedlings. Ester formulations of MCPA, 2,4-D, 2,4,5-T, mecoprop, dichloroprop, silvex, 2,4-DB, MCPB, and 2,4,5-TB were compared with an amine of MCPA. The most effective compounds were the esters of MCPA, followed by silvex.

Several herbicides were compared with paraquat for their effectiveness in providing rapid defoliation of whitebrush. Paraquat always provided the most rapid defoliation and also the highest percentage of defoliation within 2 wk. after treatment. Sodium cacodylate was an active compound, but was not so effective as paraquat.

The effect of additives in a herbicidal solution was also studied on whitebrush seedlings. Ammonium thiocyanate enhanced the activity of picloram and MCPA, but gibberellic acid was antagonistic to MCPA. Phosphon, kinetin, TIBA, and diglycolic acid, added to MCPA, were also evaluated on whitebrush. None of these combinations enhanced the activity of MCPA.

DMSO has been reported to enhance the activity of many biologically active chemicals. When added to herbicides, DMSO enhances the herbicidal effect in some cases but not in others. For example, the injury ratings resulting from treatments of 1/8 pound per acre of 2,4,5-T on huisache and mesquite increased with increasing concentrations of DMSO. In other cases, the activity of 2,4,5-T and picloram was depressed by increasing concentrations of DMSO.

The one additive that was consistently beneficial was X-77 added to paraquat. Greenhouse and field experience on many different plant species showed consistently better defoliation when X-77 was added to paraquat. This does not imply that X-77 was the only effective surfactant. Some others would perform equally well.

Compounds containing a quinoline heterocyclic base were synthesized and tested for herbicidal activity. Substitutions were made on the quinoline ring, but little herbicidal activity was found in these compounds. Compounds containing quaternary nitrogen showed activity in seedling plants but activity diminished as the plants matured.

Interactions Between Defoliants, Herbicides, and Additives

Several herbicidal combinations, including many combinations of paraquat with other herbicides, were studied using greenhouse-grown plants in an attempt to determine whether the herbicidal effects were synergistic or antagonistic, and to develop a system for predicting herbicidal interactions under field conditions.

Initial experiments on black valentine beans indicated that some herbicidal combinations decreased the effectiveness of both herbicides in the combination. A number of field observations, on the other hand, indicated that some combinations increased herbicidal effectiveness. A greenhouse study was designed in an attempt to clarify the conflicting results.

Huisache, mesquite, cotton, and beans were grown in the greenhouse and subsequently treated with foliar applications of picloram, paraquat, 2,4,5-T, and two-herbicide combinations of the three parent materials. Ratings of the treated plants were made 5 wk. after treatment. For the purpose of this discussion, when the effects of a herbicidal combination differed by 20 percent or more from the effects of a single herbicide, the activity was considered antagonistic (reduced effectiveness) or synergistic (enhanced effectiveness).

The results of the study were variable and inconclusive (table 2.1), but several statements can be made. Reciprocal antagonism (both chemicals of a pair reduced in effectiveness by the other member) occurred only once in 144 possibilities. Reciprocal synergism occurred eight times, five on woody species and three on herbaceous species. Unilateral antagonism occurred in 21 cases and unilateral synergism in 40 cases. No effect of one herbicide on the other was recorded 83 times. Thus, synergism was more prevalent than antagonism, but in most cases, one herbicide was not influenced by another. The possible effect of the herbicidal ratios that were tested was obscured by variability. One is left with the conclusion that the effectiveness of herbicidal combinations is not amenable to prediction. Each combination must be evaluated on each species to be certain of the end result.

Other experiments involving herbicide combinations on huisache emphasized the variability of results. Paraquat reduced the effectiveness of picloram, but the combination killed leaves more rapidly than comparable rates of paraquat alone. Picloram:2,4,5-T was often more effective than either herbicide alone.

Absorption and Translocation

The rate and quantity of herbicidal movement in plants have been studied primarily with radioactive tracers, which have certain well-known limitations. Until recently, no satisfactory alternative methods were known. Gas chromatographs equipped with electron capture detectors have been used for several years to detect herbicide residues in soils, forage, and animal tissues. These instruments can detect herbicides to less than 0.01 billionth

TABLE 2.1.--The effect of herbicidal combinations on phytotoxicity to four species as compared with phytotoxicity of the herbicides used alone

Herbicide	Rate	Ratio	Effect[1] of herbicidal combinations on phytotoxicity to--			
			Huisache	Mesquite	Cotton	Bean
	Lb. per acre	Lb.:lb.	- - - - - - - - -		- - - - - - - - -	
Picloram:paraquat	0.032	1:1	0 -	0 0	0 0	- 0
		1:3	+ 0	0 -	+ +	0 0
		3:1	+ -	0 -	0 0	0 0
	.064	1:1	+ 0	+ 0	+ +	+ -
		1:3	+ +	0 +	+ 0	+ -
		3:1	+ 0	+ -	+ 0	+ -
Picloram:2,4,5-T	.032	1:1	+ 0	+ +	0 0	0 0
		1:3	+ +	- 0	0 0	0 +
		3:1	+ 0	0 -	0 0	+ 0
	.064	1:1	0 -	0 0	+ 0	0 0
		1:3	0 0	0 0	[illegible] +	0 0
		3:1	+ 0	0 0	+ 0	0 0
Paraquat:2,4,5-T	.032	1:1	0 +	+ +	0 0	0 -
		1:3	0 +	0 +	0 -	- -
		3:1	0 0	+ +	0 0	0 -
	.064	1:1	0 0	0 0	- 0	- 0
		1:3	0 0	0 0	0 0	- +
		3:1	0 0	0 0	0 0	- +

[1] + = synergism, - = antagonism, 0 = no effect. The first column under a species represents the effect of the first herbicide on the second of the combination; the second column represents the effect of the second herbicide on the first of the combination.

of a gram (g.). Thus, it seemed reasonable that they could be used to supplement radioactive tracers for studying the movement and distribution of herbicides in plants.

Advantages of gas chromatography over radioactive tracers include:

1. No special safety precautions are needed for handling materials.
2. Data are easily quantified.
3. The herbicide molecule is detected rather than an atom within the molecule.

Disadvantages of gas chromatography include:

1. The herbicide must be in a volatile form or be easily converted to such a form.
2. The herbicide to be detected must contain electronegative atoms or functional groups.
3. Each portion of the plant must be analyzed separately.

A test of the gas chromatographic method was devised to study the translocation of picloram and 2,4,5-T. Black Valentine beans were germinated in sand and grown under fluorescent-incandescent light for 15 hours per day at an intensity of 900 to 1,150 ft.-c. Temperature was maintained at 38° during the light period and 32° C. during the dark period. Relative humidity was maintained between 45 and 52 percent.

Plants were treated when the primary leaves were fully expanded and the first trifoliate leaf barely visible. Twenty-four μg. of picloram or 25 μg. of 2,4,5-T were applied in 0.01 milliliter (ml.) of 1×10^{-4} molar aqueous NH_4OH uniformly over one of the primary leaves. Tween-20 was added at a rate of 0.5 percent to reduce surface tension and improve coverage. Treatments were made about 3 hours before the end of the light period.

Harvesting and sectioning were completed 4 to 4.5 hr. after treatment. Twelve samples consisting of 9 plants each were taken of leaf washes, treated leaves, stem apices, and cotyledonary node sections of the stem. Four samples of 27 plants each were taken of the roots and other portions of the stem.

The treated leaf was washed with 5 ml. of dilute NH_4OH to remove the unabsorbed herbicide. The picloram in other sections of the plant was extracted by blending the sections in acidified acetone for 2 min. in a Waring blender. An aliquot of the acetone was evaporated and the picloram taken up in 10 ml. of 0.1 normal KOH. The KOH solution was washed twice with 20 ml. of ethyl ether to remove interfering plant materials. Following acidification of the KOH solution, the picloram was extracted from the aqueous solution with four, 10 ml. portions of ether. The ether was then evaporated on a steambath and the picloram esterfied with 6 ml. of boron trifluoride-methanol solution containing 0.125 g. of BF_3 per ml. of methanol. The esterification was essentially complete if the solution was heated to dryness of a hotplate. The esterified picloram was taken up in 10 ml. of hexane and washed with 10 ml. of water. One microliter (μl.) of the hexane solution was injected into the chromatograph for determining picloram content.

The procedure for 2,4,5-T samples was the same except that other washings were omitted and no heat was applied during esterification. The methyl ester of 2,4,5-T was more volatile than the picloram ester and was lost if heat was applied. Esterification was essentially complete in 30 min. at room temperature.

The chromatograph used for all determinations was a Barber-Colman Model 5300 equipped with an electron-capture detector. Ra^{226} was the ionization source. Picloram samples were analyzed at injector, column, and detector temperatures 290° , 220° , and 250° C., respectively. The column temperature was lowered to 200° C. for the 2,4,5-T samples. Flow rate of the nitrogen carrier was approximately 75 ml. per min. for all samples.

The herbicide content was determined by comparing the peak heights of samples to the peak heights produced from known concentrations.

Table 2.2 shows the distribution of picloram and 2,4,5-T in bean plants 4 hr. after their application to one of the primary leaves. Of the 216 μg. of picloram added to the nine plants, 205 μg. (95 percent) were recovered. Eighty-five percent was recovered in the leaf wash and 6 percent in the treated leaf. Thus, less than 5 percent of the picloram was translocated, but there was a detectable amount translocated within 4 hr. to all parts of the plant except the lower portions of the roots.

Only 161 μg. (72 percent) of the 2,4,5-T was recovered in the leaf wash and 9.56 μg. (4 percent) in the treated leaf. Less than 1 μg. was found in other plant sections. Thus, almost 25 percent of the 2,4,5-T applied could not be accounted for. The missing 2,4,5-T could have been degraded, complexed, photodecomposed, or volatilized. Volatilization seems the most plausible explanation since a large surface area was involved and attempts to esterify at increased temperature resulted in low recoveries.

Concentrations of both herbicides were highest in the treated leaf (fig. 2.1). Relatively

TABLE 2.2.--The diatribution of picloram and 2,4,5-T in bean plants 4 hours after the application of 216 μg. of picloram and 225 μg. of 2,4,5-T to a primary leaf

Plant portion analyzed	Distribution in bean plant of--	
	Picloram	2,4,5-T
	- - - - μg. - - - -	
Leaf wash	185.06	161.20
Treated leaf	13.45	9.56
Apex	0.89	0.42
Stem from 4 cm. above cotyledonary node to apex	0.88	0.28
Stem 2 to 4 cm. above the cotyledonary node	0.26	0.19
Stem ± 2.0 cm. of cctyledonary node	1.43	([1])
Stem 2 to 4 cm. below cotyledonary node	0.43	([1])
Stem from 4 cm. below cotyledonary node to aand	0.86	([1])
Roots--upper	1.18	([1])
Roota--lower	([1])	([1])
Untreated leaf	0.38	([1])
Total micrograms added	216.00	225.00
Total micrograms found	204.82	171.65

[1] Nonc detectable.

high picloram concentrations were also found in the apex and near the cotyledonary node. There was a marked decrease in concentration from the cotyledonary node to the roots. The only apparent factor influencing the concentration of 2,4,5-T was the distance from point of application. Four hours appeared to be an insufficient time for a distribution to develop with 2,4,5-T.

The study shows that gas chromatographic analysis is a good technique for studing herbicide translocation. In addition, the study shows that picloram is more readily translocated than is 2,4,5-T.

The gas chromatographic and radioisotopic tracer techniques were compared in an experiment on mesquite in the field. The mesquite plants were 3 years old and were growing in an irrigated nursery. Treatments were made by pipetting 50 μg. of herbicide onto a leaf. Five adjacent leaves on a single stem constituted a treatment unit and four 5-leaf replications were used. For radioisotopic analyses, carboxy-labelled 2,4,5-T was diluted with unlabelled 2,4,5-T and water to an activity of 0.14 μc. per 50 μl. and to a concentration of 1 μg. of 2,4,5-T per μl.

The extraction and analytic procedures for gas chromatography were described above and by Merkle and Davis (14). The extraction procedures for radioisotopic analysis were the same as those used for gas chromatography. For radioisotopic analysis, the hexane portion containing methyl or butoxyethanol esters of 2,4,5-T was mixed with a scintillation solution that contained 2,4-diphenyloxazole and 1,4-bis(2-phenyloxazolyl) at concentrations of 5 and 0.3 g. per liter (l.) of toluene, respectively. The herbicide contents were determined by comparing the counts per minute of experimental samples with counts per minute of samples having a known concentration (18).

The two methods of analysis gave comparable results when the extraction, cleanup, and analytical procedures were identical (table 2.3). The amounts of 2,4,5-T in the treated leaves increased with time. The butoxyethanol ester was absorbed much more readily than was the ammonium salt.

The relative translocation rate of 2,4-D and picloram were compared in Macartney rose plants because observations had indicated widely disparate translocation patterns for the two herbicides.

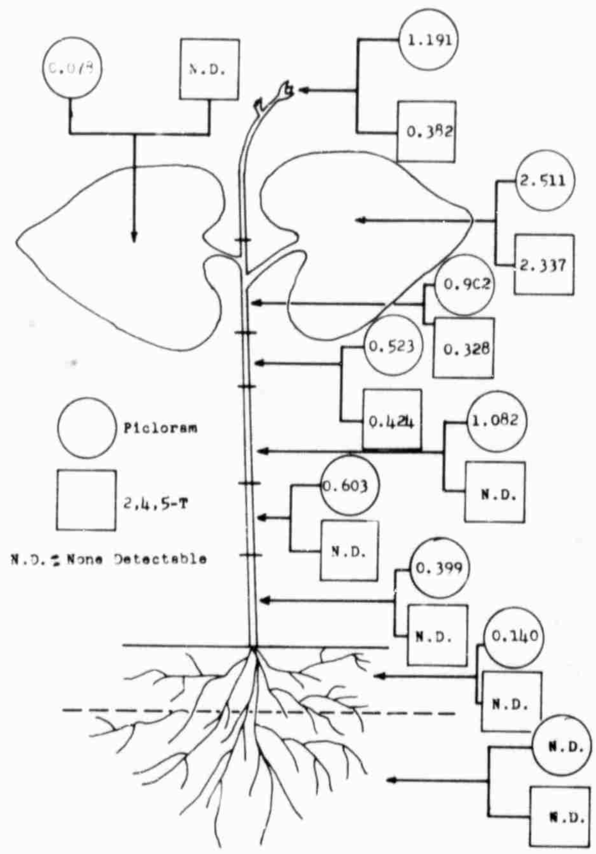

Figure 2.1.--The distribution of picloram and 2,4,5-T in bean plants 4 hours after application to the primary leaf. Numbers are nanograms per milligram fresh weight.

Macartney rose plants were dug from the field in December 1964 and transplanted into 1-gal. metal containers containing a peat moss-soil-sand potting mixture. The transplants were then kept in the greenhouse for further growth.

Treatment were made in March 1965 with the potassium salt of picloram and the dimethylamine salt of 2,4-D. Fifty μl. of herbicidal solution at concentrations of 4, 20, and 100 x 10^{-4} molar were applied to each of the 13th and 14th leaves from the stem tip. Three replications were treated for each concentration.

Visual ratings were made of chlorosis, necrosis, and defoliation of the growing tip and of leaves located apically and basally from the treated leaves. Ratings were also made of the leaves on other stems of the same plant. A rating scale of 0 to 10 was established in which 0 signified no effect and 10 signified complete chlorosis or defoliation.

The results of the study suggest that picloram was translocated to a much greater degree than was 2,4-D (table 2.4). Picloram was

TABLE 2.3.--Recovery of 2,4,5-T by radioisotopic and gas chromatographic analyses 0, 1, 6, and 24 hours after application of 250 μgs. of butoxyethyl esters and ammonium salts of 2,4,5-T to mesquite leaves

Herbicide and plant part analyzed	2,4,5-T recovered by--							
	Radioisotopic analysis				Gas chromatographic analysis			
	0 hr.	1 hr.	6 hr.	24 hr.	0 hr.	1 hr.	6 hr.	24 hr.
	μg.							
Butoxyethyl esters:								
Hexane leaf wash	201.8	119.3	44.3	12.5	202.4	162.3	81.1	34.6
NH_4OH leaf wash	29.7	47.8	19.5	31.7	21.8	37.9	17.7	13.8
Extract of treated leaves	18.5	55.3	124.9	150.2	25.8	49.6	115.2	112.7
Stem supporting treated leaves	0.0	0.1	0.6	0.2	0.0	0.4	1.1	2.0
Total recovered	250.0	222.4	189.3	193.6	250.0	250.2	215.1	163.1
Ammonium salts:								
NH_4OH leaf wash	249.0	185.9	93.1	21.0	245.8	194.3	107.6	27.0
Extract of treated leaves	1.0	16.0	43.2	75.2	4.6	13.2	65.2	61.5
Stem supporting treated leaves	0.0	0.2	0.1	0.2	0.0	0.4	1.1	2.0
Total recovered	250.0	202.1	136.4	96.4	250.0	207.9	173.9	90.5

TABLE 2.4.--Responses of Macartney rose to treatments with picloram and 2,4-D. Ratings were made 14 days after treatment

Herbicide	Concentration	Ratings of plants portions			
		Growing tip	Apical leaves	Basal leaves	Leaves on other stems
	10^4 molar				
Picloram	4	2.2	5.2	4.7	2.3
	20	5.0	8.2	5.7	7.7
	100	4.7	9.7	10.0	6.3
2,4-D	4	0.3	0.7	0.8	0.7
	20	0.0	0.7	0.5	0.7
	100	2.3	2.2	3.3	0.7

translocated apically, basally, and to other stems of the same plant in adequate amounts for phytotoxicity. The ratings for plants treated with 2,4-D were much lower, suggesting that less of this herbicide was distributed throughout the plant.

The data suggest that one reason for the greater phytotoxicity and greater bud suppression provided by picloram is its greater mobility in plants.

Many experiments have shown that phenoxy herbicides, applied to the foliage, are translocated with photosynthate. Thus, an understanding of photosynthate movement is important for an understanding of the translocation of phenoxy herbicides. The following experiment was conducted to compare the translocation pattern of sucrose with that of several herbicides.

Radioisotopic tracers were applied to greenhouse-grown mesquite and also to mesquite, live oak, and winged elm growing in an irrigated nursery. C^{14}-labelled urea with a specific activity of 7.17 millicuries (mc.) per millimole (mM) was used as a source of photosynthate. It had been previously shown (4) that urea was hydrolyzed to ammonia and carbon dioxide in cotton leaves. The carbon dioxide was then used for sugar synthesis, with sucrose being the predominant sugar. Although there was no direct information that the same cycle takes place in woody plants, sucrose was the only sugar detected in other work on mesquite (21).

C^{14}-labelled 2,4-D, 2,4,5-T, and dicamba with specific activities of 7.37, 5.13, and 1.89 mc. per mM, respectively, were the herbicides used in the study.

Greenhouse-grown mesquite plants were treated with 0.5 μc. per plant in a total volume of 25 ml. Plants were divided into three groups. Applications were made to the cotyledons in the first group, to unifoliate leaves in the second group, and to the first difoliate leaf in the third group. Plants were harvested 24 hr. after treatment, frozen, and subsequently autoradiographed.

C^{14} from urea was readily translocated from the cotyledons to all parts of the plants. However, when urea was applied to the unifoliate leaf, no C^{14} was detected outside that leaf until after the primary leaf was completely expanded. Essentially the same results were obtained from treatments to the first difoliate leaf. Translocation of 2,4,5-T occurred readily from the cotyledons, but the amount of C^{14} detected was much less than for urea. Movement of 2,4,5-T from unifoliate and the first difoliate leaves occurred somewhat more slowly and in lesser quantity than was the case for urea.

This research did not explain whether the inability of immature leaves to translocate sucrose and 2,4,5-T to other parts of a seedling is due to poorly developed vascular bundles or to the utilization of photosynthate within the treated leaf. The importance of the research is that translocation from an immature treated leaf did not occur until after that leaf was completely expanded. This emphasizes the importance of delaying field applications until after leaves have reached full size.

Labelled 2,4-D, 2,4,5-T, and dicamba were applied to leaves of mesquite, live oak, and winged elm growing in an irrigated nursery. All treatments were made with 100 μl. of total solution containing 2.0 μc. of C^{14}. Treatments were applied August 29, 1964, at the end of a hot, dry period when plants were not actively growing. Additional treatments were made September 14 after good rainfall so new leaves and shoots were developing. Plants were harvested 24, 48, and 72 hr. after the August treatment and 24 hours after the September treatment.

Only limited translocation of all materials occurred from treatments made August 29. Urea was the most mobile compound, but no C^{14} was detected in the stems at ground level. No significant differences were noted between species or between times after treatment.

Translocation of all compounds was greater from the treatments made in September. Herbicides were translocated farther and in greater quantities than they were after the August treatments. C^{14} was detected in bark from the soil level following the September treatment, whereas none was detected after the August treatment.

This study points out the necessity of growth and active photosynthesis for translocation in woody plants.

Patterns of movement in the water-conducting tissue, the xylem, were studied in mesquite, yaupon, winged elm, whitebrush, post oak, and blackjack oak with the use of methylene blue dye. The pattern and degree of movement varied widely among six species studied; but, in general, the dye was translocated only by the outermost xylem rings. Dye movement did not occur at night, and only to a very limited extent under conditions of extreme moisture stress. These observations suggest that water movement within woody plants is confined mostly to the youngest xylem tissue.

Environmental Effects on Herbicide Toxicity

Seasonal susceptibility is an inherent problem in the defoliation and control of woody species. A herbicide that provides excellent control when applications are made during one season of the year can be, and often is, virtually ineffective when applied during a different season. The problem, from the standpoint of field tests, is discussed at length in Chapter 9. Environmental variables, such as soil type, availability of soil moisture, temperature, and relative humidity, have an important bearing on susceptibility to herbicides. In most cases, however, the environmental variables are primarily important because of their influence on phenologic development, which in turn is an expression of physiological status. Predictability of seasonal susceptibility is not possible without an understanding of the physiological processes that govern the response of a plant to a herbicide.

Data from field studies (8, 11) indicated that the application of herbicides during periods of low soil moisture usually resulted in reduced kill of plants and suggested moisture as an important factor limiting herbicidal effectiveness. Less effectiveness may be due to reduced absorption or translocation of the herbicide or to some factor unrelated to herbicide movement. Even if the major effect of moisture stress is on herbicide movement, the distribution of all herbicides may not be affected in the same manner or to the same extent.

Moisture stress reduced translocation of 2,4-D in beans but did not affect absorption (1, 19). However, moisture stress decreased absorption of 2,4-D in soybeans and corn (10).

Since soil moisture is not the only factor affecting the water economy of plants, it was desirable to measure the development of moisture stress within the plant. Thermoelectric methods for measuring sap velocity have been investigated for several years (7, 12). Swanson (20) gave a detailed description of the instrumentation required for making thermoelectric measurements of sap velocity in woody plants. It appeared that with certain modifications this method could also be used to indicate the development of moisture stress in herbaceous plants via a decrease in relative sap velocity.

An experiment was conducted on the effect of moisture stress, as determined by thermoelectric methods, on the translocation of picloram and 2,4,5-T in Black Valentine beans. Gas chromatography was used to determine the herbicide content in various portions of the plant.

Bean plants were germinated and grown in moist sand under fluorescent-incandescent light with an intensity of 900 to 1,150 ft.-c. for 15 hr. per day at a temperature of 38° C. and a relative humidity of 45 to 52 percent. The temperature during the 9-hr. dark period was 32° C. Plants were thinned 2 days after emergence to three plants per pot.

Water was withheld from a number of plants until visible wilting occurred to determine whether moisture stress developed uniformly. Under the conditions described, more than 95 percent of the plants wilted within a 10-hr. period.

The sensing device used in the experiment was described by Merkle and Davis (15). Details of construction are available from them on request. The precision of the sensor was determined by repeatedly moving the sensor and remeasuring sap velocity in a single plant. On the basis of the computed variance from 15 measurements, 5, 10, and 20 measurements would be sufficient to detect differences (at the 95-percent level of probability) of 12.9, 9.1, and 6.5 percent of the mean, respectively.

The relative sap-velocity values determined by the thermoelectric method were compared to values obtained by using the leaf disc method (the relative water content of a leaf disc 10 mm. in diameter before and after imbibing distilled water for 12 hr. in the dark) on plants brought under stress by the addition of mannitol or by withholding water.

For the main experiments, 36 groups consisting of 3 pots each were visually matched for similar leaf area. One pot in each group was assigned at random to one of three moisture conditions: No stress, moderate stress, or advanced stress. Plants were considered to be under moderate or advanced stress when water had been withheld for 80 and 96 hr., respectively. Thermoelectric measurements of relative sap velocity were made approximately 9 days after germination when the primary leaves were fully expanded and the first trifoliate leaf had just emerged.

Thermoelectric measurements were made on one-fourth of the plants of each treatment (27 plants), chosen at random. Stress was expressed as apparent sap velocity of the stressed plants relative to that of the control plants.

Picloram was applied about 3 hr. before the end of the light period after the determination of moisture stress. Twenty-five μg. of picloram were applied uniformly to a primary leaf in 0.01 ml. of 1×10^{-4} molar NH_4OH. Four hours later the treated leaf was washed with 5 ml. of 1×10^{-4} molar NH_4OH to remove the unabsorbed picloram. The picloram content in the leaf wash, treated leaf, apex, and cotyledonary node section of the stem was determined by gas chromotography. Nine plants were analyzed for each treatment.

The chromatograph was equipped with an electron capture detector containing Ra^{226} as the ionization source. The 4-foot spiral glass column was packed with 60 to 80 mesh Chromasorb-W, coated with 1.5 percent SE-30 oil. Nitrogen at a flow rate of 75 ml. per min. served as the carrier gas. Samples were analyzed at injector, column, and detector temperatures of 290, 220, and 240° C., respectively.

Twelve replications of each moisture stress treatment were analyzed. The picloram was extracted from the treated leaf, apices and stems by blending with 20 ml. of acidified acetone for 2 min. The plant residue was suction-filtered through Whatman No. 1 filter paper, combined with the extract and washed with an additional 20 ml. acidified acetone.

An aliquot of the acetone was evaporated and the picloram taken up to 10 ml. of 0.1N, aqueous NaOH. The NaOH solution was washed twice with 20 ml. portions of ether, acidified with HCl, and extracted with four, 10-ml. portions of ether. After evaporating the ether, the picloram was esterified by heating to dryness with 6 ml. of boron trifluoride-methanol solution containing 0.125 g. boron trifluoride per ml. An aliquot of the leaf wash was evaporated and esterified in the same manner. The esterified picloram was taken up in 10 ml. of hexane and washed with 10 ml. of water. One μg. of the hexane solution was injected into the chromatograph, and the picloram content determined by comparing the peak height produced to that produced by known quantities of picloram.

The procedures followed for 2,4,5-T and picloram were identical, with the following exceptions: 25 μg. of 2,4,5-T were added to each of the primary leaves (total of 50 μg.), the samples were not taken until 8 hr. after application, no heat was applied during the boron trifluoride-methanol esterification, and the column temperature of the chromatograph was reduced to 200° C.

A comparison of the thermoelectric method and leaf disc methods for determining moisture stress is shown in table 2.5. Mannitol at 0.1 and 0.2 molar concentrations reduced leaf disc turgidity about 7 and 12 percent and apparent sap velocity 28 and 91 percent, respectively. Thus, after 4 hr., sap velocity was reduced considerably more than leaf turgidity. This indicated that sap velocity was the more sensitive indicator of moisture stress. However, it was also more variable. The coefficients of variation were 2 and 29 percent for the leaf disc and thermoelectric methods, respectively.

In other experiments the two methods were compared using plants in which moisture stress was induced by withholding water. In a typical experiment, water was withheld from 10 plants matched for leaf area. After 96 hr., the average leaf turgidity was 90 percent and the sap velocity 26 percent of similar plants from which water was not withheld. Data from both methods were more variable when obtained from stressed rather than unstressed plants.

From the experiments described, it was concluded that the thermoelectric method could be used on small plants to indicate the degree of moisture stress if comparisons were made between plants of reasonably uniform leaf area and if an adequate number of measurements were made.

TABLE 2.5.--Relative leaf disc turgidity and apparent sap velocity of ten 12-day-old bean plants in sand before and 4 hours after flooding with 0.1 and 0.2 molar mannitol

Mannitol molarity	Relative leaf disc turgidity			Apparent sap velocity		
	Original	Final	Ratio	Original	Final	Ratio
	- - Percent - -			- Cm. per hour -		
0.10	81.8	75.9	0.927	9.79	7.06	0.721
.20	82.4	72.9	.885	10.01	.90	.090

There was no apparent effect of moisture stress on absorption of either picloram or 2,4,5-T (table 2.6). There was no significant change in the picloram or 2,4,5-T content of the leaf wash at any moisture stress nor in the content of either herbicide in the treated leaf. However, the translocation of both herbicides was reduced by moisture stress.

Picloram was translocated upward to the apex and downward to the stem in the no-stress plants at approximately the same rate. Upward translocation of 2,4,5-T occurred twice as rapidly as did downward translocation. It should be pointed out that the treatment rate for 2,4,5-T was double that of picloram. In addition, the data for 2,4,5-T was taken 8 hr. after application, instead of 4 hr., to allow more time for a distribution pattern to develop.

Moderate stress had no significant effect on the translocation of picloram but did on the translocation of 2,4,5-T. Apparent sap velocities indicate, however, that the moderate stress level was more severe in the plants treated with 2,4,5-T.

Advanced stress significantly reduced the translocation of both herbicides. However, translocation of 2,4,5-T was apparently more sensitive to changes in moisture stress than was the translocation of picloram.

Since both herbicides were translocated under advanced stress, it was of interest to determine whether movement could be prevented by moisture stress. Plants under moisture stress so severe that visible wilting had occurred were treated with picloram and 2,4,5-T. Under these conditions picloram was translocated to the stem and apex in amounts approximately 57 percent of that found in the

TABLE 2.6.--The amounts of picloram and 2,4,5-T present in various portions of plant subjected to different degrees of moisture stress

Herbicide[1]	Sap velocity	Leaf wash[2]	Plant fraction		
			Treated leaf	Apex	Central stem
	Percent of control	µg.	Nanograms per µg. fresh weight		
Picloram	100	185.1	2.511	1.191	1.082
	57	180.5	2.592	.983	1.068
	22	185.8	2.255	.773	.662
2,4,5-T	100	351.8	7.063	1.680	.787
	37	371.5	8.313	1.081	.565
	17	364.8	7.384	.781	.344

[1] 25 µg. of picloram applied to one primary leaf; 25 µg. of 2,4,5-T applied to each of two primary leaves

[2] Leaves treated with picloram washed 4 hr. after application; those treated with 2,4,5-T washed 8 hr. after application.

no-stress plants. The movement of 2,4,5-T into the stem was reduced below the detectable limits of the method, and to approximately 10 percent of that found in the apices of no-stress plants.

Picloram was more mobile than 2,4,5-T in bean plants. After 4 hr., as much picloram was translocated to the apex and central stem from a 25-µg. application as there was 2,4,5-T from a 50-µg. application 8 hr. after treatment.

The experiment on the effect of moisture stress on herbicide translocation in beans was later extended to absorption and transport in mesquite and winged elm (6). Plants were grown in a greenhouse for 6 wk. and then transferred to controlled environment rooms, where they remained for 7 days before treatments were made.

For experiments involving moisture stress, plants were grown in a 5:3:1 mixture of Norwood silt loam, Lakeland sand, and peat, respectively. A modified pressure membrane apparatus, calibrated in atmospheres (atm.) of tension, was used to determine moisture availability. Each pot was brought to a predetermined weight at the beginning of each light period. Soil moisture levels were maintained at one-third to one-half, 4 to 6, 10 to 12, and 18 to 20 atm. The effects of stress on both species were expressed as the dry-weight increment of top growth during a 5-day period. In addition, leaf turgidity and thermoelectric measurements were made on mesquite.

After the desired soil moisture levels were attained, herbicides were applied to two leaves of mesquite and three or four leaves of winged elm located on about the midpoint of the stem. Both herbicides were applied in 0.01 molar NH_4OH containing 2 percent of a surfactant. Fifty µg. of herbicide were applied to each mesquite leaf and 25 µg. to each winged elm plant.

Extraction and subsequent analysis by gas chromatography were the same as described for the experiment on beans. Plants were harvested 4, 24, and 90 hr. after treatment.

Foliar absorption of picloram and 2,4,5-T by winged elm was not affected by moisture stress. The same was true for absorption of 2,4,5-T by mesquite, but absorption of picloram decreased as moisture stress increased (table 2.7). But the percentage of picloram absorbed by mesquite was much higher than for 2,4,5-T. On the contrary, the relative percentages of absorption by winged elm were about the same. Mesquite absorbed much more picloram than did winged elm.

Moisture stress reduced movement into untreated tissues of mesquite, except where concentrations in non-stressed tissue were very low (fig. 2.2). In general, transport to

TABLE 2.7.--Absorption of picloram and 2,4,5-T by mesquite and winged elm as influenced by mositure stress

Moisture stress	Absorption[1] by mesquite of--		Moisture stress	Absorption[2] by winged elm of--	
	Picloram	2,4,5-T		Picloram	2,4,5-T
Atm.	Percent		Atm.	Percent	
0.5	36.1	4.2	0.4	5.0	4.1
3.8	27.1	3.7	2.5	5.0	3.9
10.5	21.8	4.5	4.7	5.1	4.2
20.8	10.0	5.5	23.8	4.8	3.5

[1] 50 μg. of herbicide applied to each of two leaves. Measurements made 14 hours after treatment.
[2] 25 μg. of herbicide applied to each plant. Measurements made 20 hours after treatment.

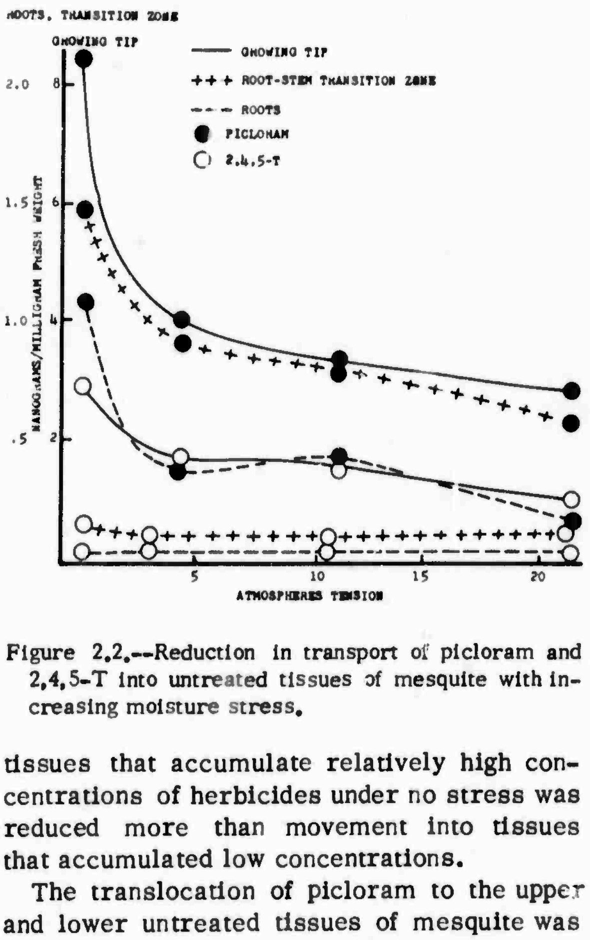

Figure 2.2.--Reduction in transport of picloram and 2,4,5-T into untreated tissues of mesquite with increasing moisture stress.

tissues that accumulate relatively high concentrations of herbicides under no stress was reduced more than movement into tissues that accumulated low concentrations.

The translocation of picloram to the upper and lower untreated tissues of mesquite was reduced by moisture stress by about the same percentage, even though the total amount detected in the growing tips was greater than in the roots. The most severe stress level reduced concentration in the roots by about 85 percent. Nevertheless, the amount of picloram detected in mesquite tissues under

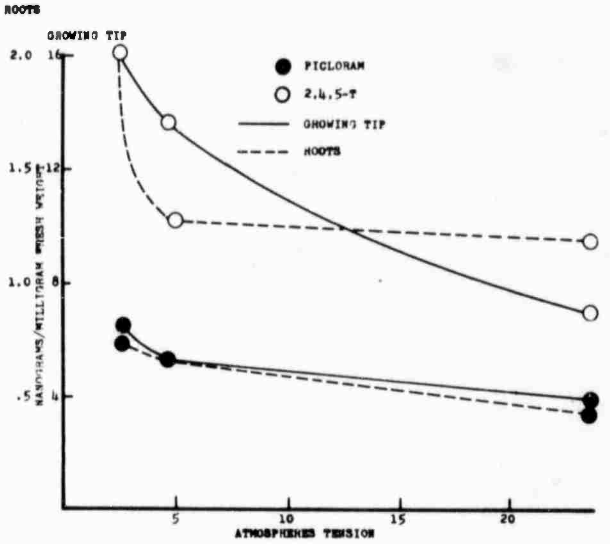

Figure 2.3.--Reduction in transport of picloram and 2,4,5-T into untreated tissues of mesquite with increasing moisture stress.

the most severe moisture stress was higher than for 2,4,5-T with no stress.

Movement of 2,4,5-T to the growing tip was reduced by maximum moisture stress by about the same percentage as for picloram (fig. 2.2). Very little 2,4,5-T was detected in the roots and the root-stem transition zone so the effects of moisture stress could not be adequately determined.

The transport in winged elm was much different than in mesquite (fig. 2.3). Picloram was found in both roots and growing tips and the concentration did not decrease as markedly with increasing moisture stress. The transport of 2,4,5-T was much greater in winged elm than in mesquite. High concentrations were detected in both the growing tip and in the roots. The concentration of 2,4,5-T in the growing tip decreased gradually with increasing moisture stress, whereas concentration in the roots decreased sharply from 0 to 5 atm. tension and then remained about the same through 20 atm. tension.

Thus, moisture stress appears to be a significant factor limiting herbicide movement in woody plants, but the limiting effect is not constant with species or with herbicide. In general, the greatest reductions in transport occurred between 0 and 5 atm. tension, reducing gradually thereafter.

The absorption of picloram and 2,4,5-T by 10 woody species was studied to determine the relationship between susceptibility and the rates and amounts of herbicide absorbed. Herbicides were applied to the upper surface of leaves. Fifty μg. in 100, 1-μl. drops, were applied so that the distance between drops was approximately four times the initial diameter of a drop. Five leaves were treated in most cases, but two to ten leaves were used for species with very large or small leaves.

Picloram usually entered more rapidly and in greater amounts than 2,4,5-T (table 2.8). There are several examples that can be cited to indicate that there is no particular relationship between the amount of herbicide absorbed and susceptibility of that species to either of the herbicides. Saw greenbriar absorbed picloram as well as did live oak, but saw greenbriar is much more resistant to picloram. In like manner, mesquite absorbed more picloram than any other species, but it is quite resistant to picloram. Winged elm and Macartney rose absorbed appreciably more 2,4,5-T than did post oak, even though both are less susceptible to 2,4,5-T.

The two herbicides were also applied to upper and lower leaf surfaces to determine if differential uptake occurred. The same application technique was used as in the previous experiment. The leaves were rinsed after 6 hr. and the herbicide content of the leaves determined.

Stomata are absent on the upper surfaces of live oak, saw greenbriar, and yaupon, whereas they are abundant in mesquite and winged elm. There was a relationship between stomatal density and the amount of herbicide absorbed. It is well to point out, however, that stomatal entry is not the only avenue for absorption into a leaf. Direct cuticular absorption and entry through trichomes have also been reported and are believed to occur commonly.

Paraquat was the most promising herbicide tested for rapid defoliation of woody species. There were cases, however, when it was not an effective defoliant. Previous studies had shown that the phytotoxicity of paraquat was reduced when applied at low temperatures (16) and that photodecomposition occurred readily (9). The following studies were designed to evaluate the effects of temperature and plant species on the phytotoxicity of paraquat (2).

The effects of temperature were tested on oats, winter peas, huisache, and mesquite plants in growth chambers with environmental control. A small atomizer was used to apply 120 μg. per μl. to each plant. Temperature effects were also studied on yaupon growing in the field. In this case, temperature was determined from a thermograph located at the test site. The temperature measurements were expressed as the accumulative degree hours above 5° C.

Temperatures of 5° to 6° C. in the growth chamber, compared to higher temperatures, reduced the rapidity of leaf necrosis on all species 48 hr. after treatment (table 2.9). After 96 hr., however, all species showed considerable necrosis even at the low temperatures. The results of the field experiments

TABLE 2.8.--The absorption of picloram and 2,4,5-T by 10 woody species 14 and 48 hr. after application

Species	Ratio of herbicide content[1]			
	14 hr. after applying--		48 hr. after applying--	
	Picloram	2,4,5-T	Picloram	2,4,5-T
Black brush	0.094	0.014	0.121	0.015
Live oak	.005	.006	.017	--
Macartney rose	.094	.035	.108	.036
Mesquite	.239	.019	.162	.034
Poplar	.037	.007	.087	.026
Post oak	.037	.013	.057	.024
Saw greenbriar	--	.001	.021	.009
Sycamore	--	.008	--	.013
Winged elm	.075	.031	.138	.030
Yaupon	--	.006	.031	.017

[1] Herbicidal content is expressed as micrograms of herbicide in treated leaves and attached stems divided by micrograms of herbicide in the leaf rinse.

TABLE 2.9.--The effect of temperature on the percentage of leaf necrosis 48 and 96 hr. after treatment resulting from treatments with paraquat

Species	Time after treatment	Leaf necrosis at temperatures of--			
		5° to 6° C.	13° to 14° C.	24° to 26° C.	33° to 35° C.
	Hr.	Percent			
Huisache	48	17	38	100	92
	96	62	100	100	88
Mesquite	48	53	63	90	80
	96	83	83	97	90
Oats	48	50	80	80	73
	96	70	93	83	63
Winter peas	48	27	80	70	60
	96	90	87	83	80

on yaupon paralleled those in the growth chambers. The effectiveness of paraquat was reduced when applied at lower air temperatures, but there was little difference among treatments after 40 days.

In a companion experiment, plants were washed at intervals after treatment to determine what effect rainfall soon after treatment would have. Paired yaupon plants growing in the field were treated with paraquat at 12 lb. per acre. Applications were made to the whole plant with a 3-nozzle sprayer when temperatures were 0°, 5°, and 18° C. One of the paired plants was washed with water at 0, 1/2, 1, and 24 hr. after treatment to remove the paraquat and determine the length of time required for absorption.

Yaupon showed no differences in leaf injury 10, 20, and 40 days after application when plants were not washed, regardless of air temperatures at the time of treatment (table 2.10). Leaf injury was not as high as washed plants, except for those washed 24 hr. after treatment. Plants that were washed immediately had only slight necrosis 10 days after treatment, but after 40 days the percentage of necrosis had increased appreciably.

Low temperature appeared to reduce the percentage of leaf necrosis 10 and 20 days after treatment on plants that were washed 1/2 and 1 hr. after the paraquat was applied. Forty days after treatment, however, the percentage of leaf necrosis was almost as high on plants maintained at the lowest temperature as at the highest. When washing was done 24 hr. after treatment, temperature had only a slight effect on leaf necrosis. The three temperatures tested did not influence leaf necrosis on unwashed plants.

The data indicate that absorption of some paraquat occurs immediately. If a heavy rainfall did not occur until 1/2 hr. after treatment, the rapidity of action would be reduced, but after 40 days a high percentage of necrosis could be expected.

TABLE 2.10.--Percentage of leaf necrosis of yaupon 10, 20, and 40 days after treatment with 12 lb. per acre of paraquat, at air temperatures of 0, 5, and 18° C.

Plants[1]	Air temperature	Leaf necrosis of yaupon		
		10 days after treatment	20 days after treatment	40 days after treatment
	°C.	- - - - - -Percent - - - - -		
Washed after treatment:				
0......hr...	0	3	26	67
	5	5	12	70
	18	8	28	61
1/2.....hr...	0	40	42	86
	5	29	40	87
	15	84	90	97
1......hr...	0	56	64	82
	5	55	31	82
	18	74	83	94
24......hr...	0	88	92	98
	5	96	99	99
	18	99	100	100
Unwashed.........	0	97	100	100
	5	98	100	100
	18	100	100	100

[1] One plant of two was washed 0, 1/2, 1, and 24 hr. after treatment.

The absorption experiments were continued on other species. Winged elm, live oak, and mesquite growing in the field were treated in September and October 1966. Ten leaves were selected for each treatment. Paraquat was applied with a pipet at 9.5 μg. per leaf to winged elm and mesquite and 14.3 μg. per leaf to live oak, in 0.2 and 0.3 ml. of water, respectively. The paraquat was washed off the leaves with water 10, 20, 40, and 60 min. after application. Each leaf was evaluated daily for 7 days by estimating the percentage of leaf necrosis. The effectiveness of the washing procedure was checked by applying paraquat and washing immediately. Injury to the washed leaves was compared with injury to unwashed leaves.

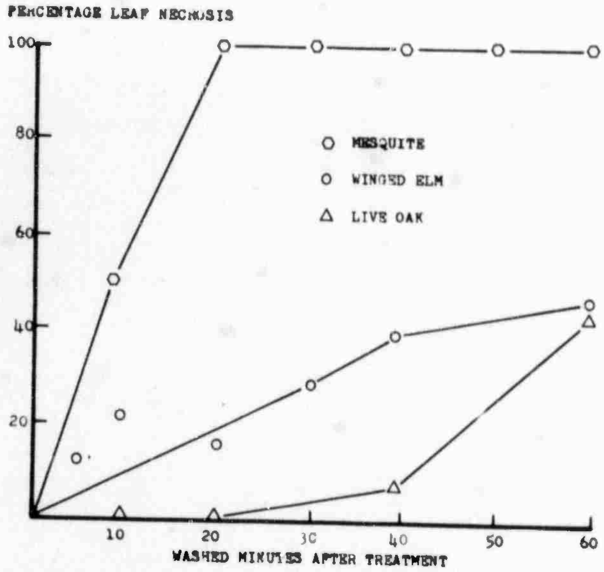

Figure 2.4.--The effect of washing on the phytotoxicity of paraquat on live oak, winged elm, and mesquite leaves. Injury ratings were made 7 days after treatment.

The absorption rates varied with species (fig. 2.4). With an absorption time of 20 min. injury to leaf tissue was 100, 15, and 0 percent on mesquite, winged elm, and live oak, respectively. The injury to winged elm and live oak leaves increased to 40 percent for an absorption period of 1 hour. Necrosis of unwashed leaves of live oak and winged elm was 83 and 85 percent, respectively, 7 days after treatment, but never attained 100 percent as did mesquite.

The studies on the absorption of paraquat show that absorption varies widely among species. A 20-min. absorption period is adequate for some species, but an hour is required for others. Low temperature reduces paraquat activity, as measured by leaf necrosis, if leaves are washed a short time after treatment, but temperature does not influence unwashed plants.

Anatomy and Morphology of Woody Plants

The anatomy and morphology of woody plants had a direct bearing on the susceptibility of woody plants to herbicides. Future chapters will discuss the importance of phenologic development in determining the period of maximum susceptibility to herbicides. Anatomic-morphologic investigations are an extension of phenology in that they provide a more detailed knowledge of leaf and stem characteristics that are related to herbicidal absorption and translocation. Thus, anatomy and morphology lead to a more complete understanding of a woody species and aid in the interpretation of results that are obtained from greenhouse and field experiments.

The bulk of the anatomical research was conducted on mesquite and was only partly supported by ARPA. Leaf, stem, and root tissue of mature trees, small plants in the greenhouse, and seedlings were analyzed in great detail. In addition to the anatomic research on mesquite, a study was begun to compare the growth structure of the major woody plants in Texas. Samples were taken from 95 woody species in 37 plant families found in the Piney Woods, Gulf Prairie, Edwards Plateau, South Plains, and Post Oak Savannah regions of Texas.

The discussion of anatomical and morphological research will be limited almost entirely to the leaves. A plant leaf represents a major pathway of herbicidal absorption and translocation. Thus, the leaf tissues are of primary importance for determining the reaction of a woody species to treatments with herbicides.

The development of mesquite leaves in the spring, in terms of both number and size, was different for leaves produced on new stems of the current season than on wood from previous seasons (17). New wood produced one leaf per node, the older wood of the terminal three or four nodes produced about two leaves per node and fewer than that were produced on the older nodes. Development of leaves usually started earlier in the season on older wood than on wood of the current season, but leaf expansion occurred over a longer period of time. Leaves on the new wood were initiated and fully expanded within a 10-day period. On older wood, however, leaf development was initiated earlier and in some cases continued over a period of 2 months. Because of the longer period of expansion, the leaves on the older wood were also larger than those on the wood of the current season. Leaf growth on the new wood was arrested at the same time as stem elongation stopped.

Leaf development is one of the criteria commonly used to determine the period of maximum susceptibility. Most woody plants are susceptible at a time when the leaves have reached full size and terminal twig elongation has stopped. Because more leaves are produced on old wood than on new wood, the leaves occurring on the old wood should be examined more closely to determine susceptibility.

The length of new stems can vary widely on the same tree (fig. 2.5). In 1963, the number of new nodes on branches of one tree varied from a low of 5 to a high of 16. The total length of new stem growth varied from 8 to 40 cm. The cessation of terminal twig elongation was very abrupt. Elongation occurred rapidly from early March to the latter part of April, then stopped abruptly and no more growth was recorded for the following 3 mo. The recommendation for the herbicidal control of mesquite in Texas states that spraying should not be started before 40 days after the initiation of new leaves. That recommendation relates closely to the termination of stem elongation.

The thickness of the cuticle on leaves and petioles is an important consideration for the chemical control of mesquite, because the cuticle acts as a barrier to absorption of the herbicide. New leaves do not have cuticle as they start to expand but cuticle development begins soon thereafter and increases gradually for a period of several months. The leaf trans-sections in figure 2.6 show that no cuticle was visible on a leaf collected March 28, but the cuticle was well developed on a leaf collected April 24. Cuticle development on April 24 was apparent only on the upper surface of the leaf, however. None could be seen on the lower surface. The development of cuticle began about April 18, ultimately resulting in layers about 6 and 2 μ thick on the upper and lower surfaces, respectively.

The number and location of stomata are also important because they may influence the amount of herbicidal absorption. In mesquite leaves, about 20,000 stomata per square cm.

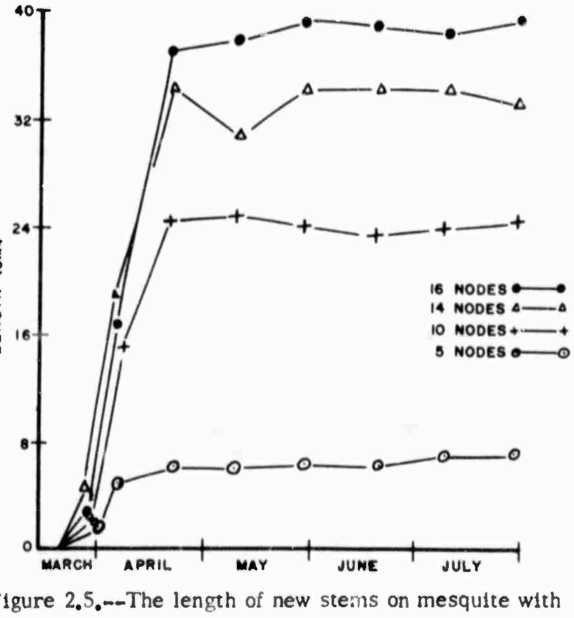

Figure 2.5.--The length of new stems on mesquite with a varying number of nodes

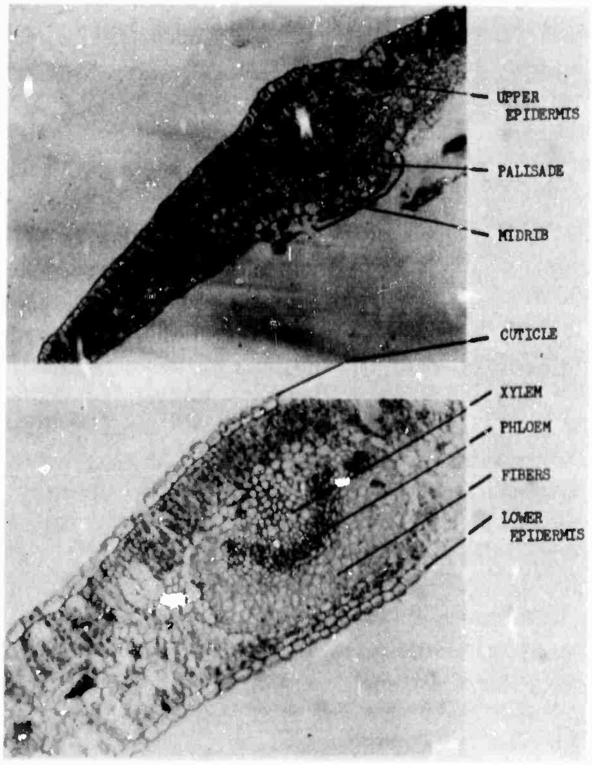

Figure 2.6.--Trans-sections of mesquite leaflets on March 28 (top, X 78) and April 24, 1963 (bottom, X 114).

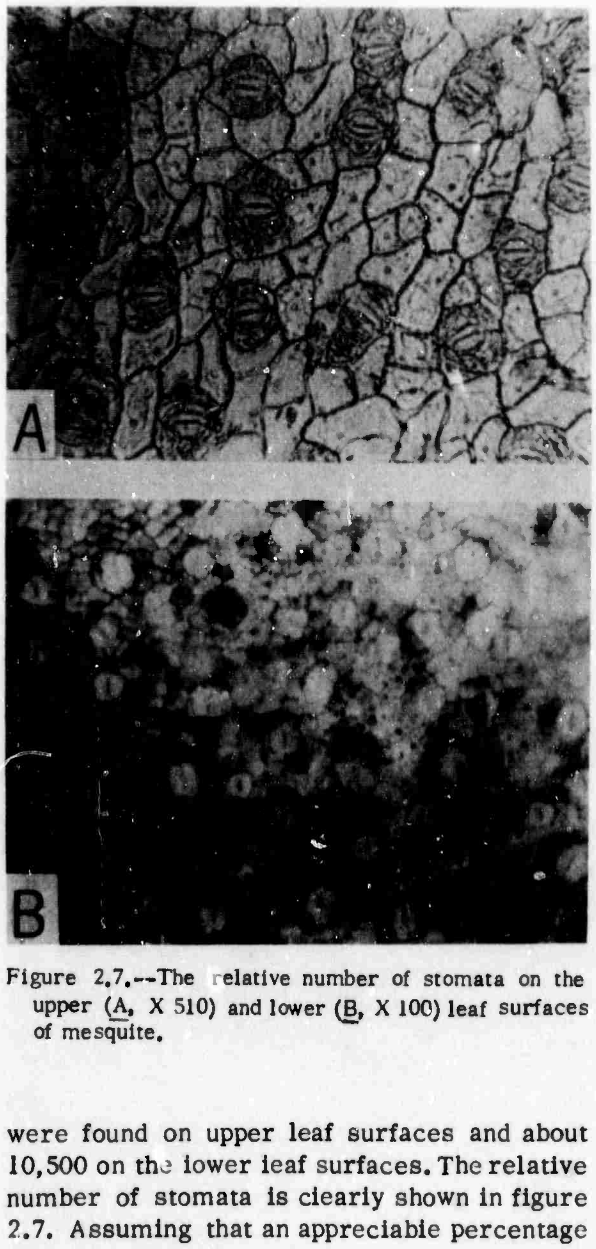

Figure 2.7.--The relative number of stomata on the upper (A, X 510) and lower (B, X 100) leaf surfaces of mesquite.

were found on upper leaf surfaces and about 10,500 on the lower leaf surfaces. The relative number of stomata is clearly shown in figure 2.7. Assuming that an appreciable percentage of herbicidal entry does occur through the stomata, a much greater amount of absorption by mesquite would be expected from herbicide deposited on the upper leaf surfaces.

The anatomical and morphological work on mesquite has emphasized the importance of detailed plant characteristics that influence herbicidal absorption and translocation. Stem elongation and leaf and cuticle development support observations that have been made in the field and attest to the importance of making mesquite treatments at the proper season of the year.

The translocation zone in the trunk of mesquite is not more than 3 mm. thick. The translocating phloem is about 0.3 mm. thick and the active translocating xylem, the outermost ring, is about 2mm. thick.

Another important and interesting aspect of the relationship between herbicidal activity and anatomical detail is that starch grain counts in plant tissue generally agree with known carbohydrate cycles. In the new wood of mesquite, starch appeared in the xylem and pith in June after elongation had stopped. Starch had disappeared in 1-year-old wood by April 6 when new shoots were being produced and then starch again appeared in May. Starch grains were found all year in the trunks, the lowest concentrations in April and early May. In roots, starch grain counts were lowest in April and then returned to a uniform concentration in May. No starch grains were found in the phloem or periderm of any root sections.

The data on starch grains found in the stem of mesquite also parallel the period at which mesquite is most susceptible to herbicides. Starch disappeared in 1-year-old wood in early April, which is the time when new leaves are rapidly expanding. This suggests that the mass flow of carbohydrates is progressing acropetally, and any phenoxy herbicide that was absorbed by the plant would, in general, move with the mass flow of the carbohydrates. Starch grains were again observed in the 1-year-old wood in May. At this time, leaf expansion has stopped and stem elongation has been arrested so that the mass flow of carbohydrates is reversed to a basipetal direction. Absorbed herbicides would travel to the base of the plant with the carbohydrate flow and ultimately reach active sites for killing the entire plant.

Radial stem enlargement occurs after stem elongation has stopped. Susceptibility to herbicides is closely correlated with the period of stem enlargement in mesquite. Thus, the work on the anatomical and morphological details of mesquite has supported observations and experience from field applications.

Mechanisms of Herbicidal Actions

Paraquat is an effective herbicide known for its rapidity in defoliating certain woody plants. This indicated that environmental factors are of considerable importance in determining the herbicidal potential of these compounds. Light enhances the herbicidal effectiveness of certain dipyridilium cations (13), and oxygen is required if toxic symptoms are to occur in plants (3). For this reason, experiments were conducted to determine the effect of light, oxygen, and temperature on a representative of the dipyridilium herbicides (5). The plant species used included mesquite, bean, honeysuckle, elodea, and duckweed.

Cool, white fluorescent tubes were used as the light source for all experiments. Light intensity was determined with a Weston cell. In experiments in which oxygen was excluded, the nitrogen source was pre-purified and, after an initial flushing of 30 sec., was applied at a pressure of 5 lb. per sq. in.

The effect of paraquat on plant pigments was determined from the emission spectra of leaf extracts in a spectrophotometer. Ten grams of immature leaves were blended with 100 mm. of water in a Waring blender for 2 min. The green homogenate was suctioned, filtered, and exposed to various light intensities, oxygen pressures, and paraquat concentrations. After treatment, pigments were extracted from the aqueous solution with ether and the emission spectra of the ether portion determined.

Changes in membrane permeability were determined with a conductivity bridge and a low conductivity-type cell having an approximate cell count of 0.17 reciprocal cm. Undamaged, immature leaves were placed in paraquat solution having an electrical resistance of approximately 700 ohms. A decrease in the electrical resistance of the solution was considered to be an indication of leakage of materials from the leaves due to changes in membrane permeability.

Since the activation of paraquat appeared to be related to the formation of a free radical, the possibility existed that the effect of light was a direct chemical effect because light, especially at shorter wavelengths, often enhances free-radical reactions. To test this possibility, various parts of mesquite plants were submersed in a solution containing 150 p.p.m. paraquat and were exposed to direct sunlight. When the leaves were illuminated, discoloration was observed after 24 hr. even though the roots and nutrient solution remained in darkness. Little discoloration was observed when the nutrient solution was illuminated but the leaves kept in darkness. Enclosing the leaves in a dark container undoubtedly gave reduced transpiration and consequently, the upward movement of solutes. Thus, the lack of activity could have resulted from a lack of translocation rather than a lack of chemical activitation. To eliminate this possibility, duckweed, a small aquatic plant, was enclosed in a light-proof photographic developing box which was lowered and raised from an illuminated solution containing 100 p.p.m. paraquat, several times per minute. This insured a continuous supply of illuminated paraquat. However, no bleaching occurred. It is, therefore, apparent that the plant leaves must be exposed to direct light before a maximum effect from paraquat is obtained. This supports the hypothesis that the effect of light is indirect in that it affects herbicidal activity only as it affects some physiological process.

If the activity of paraquat is directly related to some physiological process, then a plant having a low light requirement for maximum physiological activity should be as susceptible to paraquat at low light intensity as it is at high light intensity.

Sprigs of elodea, a plant capable of rapid growth and reproduction at low light intensity, were grown in a nutrient solution at light intensities of 65 ft.-c. and full sunlight for 2 wk. Paraquat reduced growth at both light intensities, but the action was more rapid at full sunlight. In full sunlight the first symptom of injury was bleaching which began at the growing tip and proceeded down the stem. The stem lost its turgidity and the plant collapsed. At 65 ft.-c., there was very little bleaching and collapse was slower. Since elodea grew rapidly at 65 ft.-c., it was physiologically active; but treated plants did not show severe paraquat damage. Thus, a precise correlation between physiological activity and paraquat activity did not exist.

Following the observation that high light intensities were required for bleaching action of paraquat in vivo, experiments were conducted in vitro to determine the conditions necessary for the rapid bleaching of an aqueous extract of bean leaves. Paraquat produced no bleaching of the extracts in darkness, nor in light when oxygen was replaced by nitrogen. Since both light and oxygen were required, it is likely that paraquat enhanced the photo-oxidation of plant pigments. Enhancement of photo-oxidation may come about through the destruction of a membrane or a protective enzyme system because boiling also produces a rapid bleaching under similar conditions.

The influence of light on paraquat's ability to alter the permeability of plant membranes is shown in table 2.11. Resistance was decreased markedly when paraquat was added to water containing leaves of three plant species. The reduction of resistance was much less in the dark. The decrease in resistance is assumed to have occurred as a result of leakage of cellular materials through membranes damaged by paraquat. The effect on membranes, unlike the bleaching of the pigment system, did not require the presence of any appreciable amount of oxygen, but was temperature dependent (table 2.12).

The data indicate that light and oxygen are essential for rapid bleaching of the plant pigment system by the paraquat. This bleaching does not appear to be directly related to physiological activity, but to the destruction of a protective system that normally prevents photo-oxidation. Light and temperature, but not oxygen, are also essential for the changes in membrane permeability brought about by paraquat.

Picloram is a relatively new herbicide that is highly phytotoxic to a broad array of plant species. Knowledge of its mode of action would be extremely helpful. In that regard, the effect of picloram on various components of intermediary metabolism was studied. The research reported here is an investigation of the inhibition by picloram of dehydrogenases that are linked to the oxidized (NAD) and reduced (NADH) forms of nicotineamide-adenine dinucleotide. The dehydrogenase systems that were studied include (1) alcohol, (2) glucose-6-phosphate, (3) glutamic acid, (4) lactic, and (5) malic.

Malic dehydrogenase isolated from mesquite seedlings was used in the first studies. Double reciprocal plotting of velocity and substrate concentration showed that picloram was competitive with both NAD and NADH (fig. 2.8). Inhibition occurred in all of the dehydrogenase systems. Double reciprocal plotting for glucose-6-phosphate and alcohol dehydrogenase indicated that picloram was competitive with NAD in a like manner to the original observations on malic dehydrogenase.

Antagonism, or competitive inhibition, may occur in several ways. The inhibitor may combine with the free enzyme, reversibly or irreversibly, at the site normally reserved for the NAD. The inhibitor may also combine directly with NAD and reduce the effective NAD concentration, thus slowing the reaction. Or the inhibitor-NAD complex may itself be inhibitory to the enzyme.

The mechanism of inhibition was studied further by single curve plotting in which (S) is plotted against I(1-i)/i, when I = concentration

TABLE 2.11.--Reduced electrical resistance resulting from damage to plant membranes by paraquat

Species	Paraquat concen- tration	Light intensity	Electrical resistance after leaf immersion of--		
			0 hr.	24 hr.	30 hr.
	P.p.m.	Ft.-c.	- - - -	Ohms	- - - - -
Mesquite	0	Dark	750	700	675
		500	750	675	640
	100	Dark	800	685	675
		500	800	485	470
Honeysuckle	0	Dark	775	760	725
		500	785	730	625
	100	Dark	850	800	750
		500	850	560	430
Bean	0	Dark	750	660	635
		500	750	625	575
	100	Dark	760	650	550
		500	760	250	220

TABLE 2.12.--The influence of temperature on paraquat damage to the membranes of bean leaves as determined by reduced electrical resistance

Paraquat concen- tration	Temperature	Electrical resistance after leaf immersion of--	
		0 hr.	24 hr.
P.p.m.	°C.	- - - - - Ohms	- - - - - -
0	8	650	507
	25	650	558
	37	650	568
100	8	650	448
	25	650	360
	37	650	335

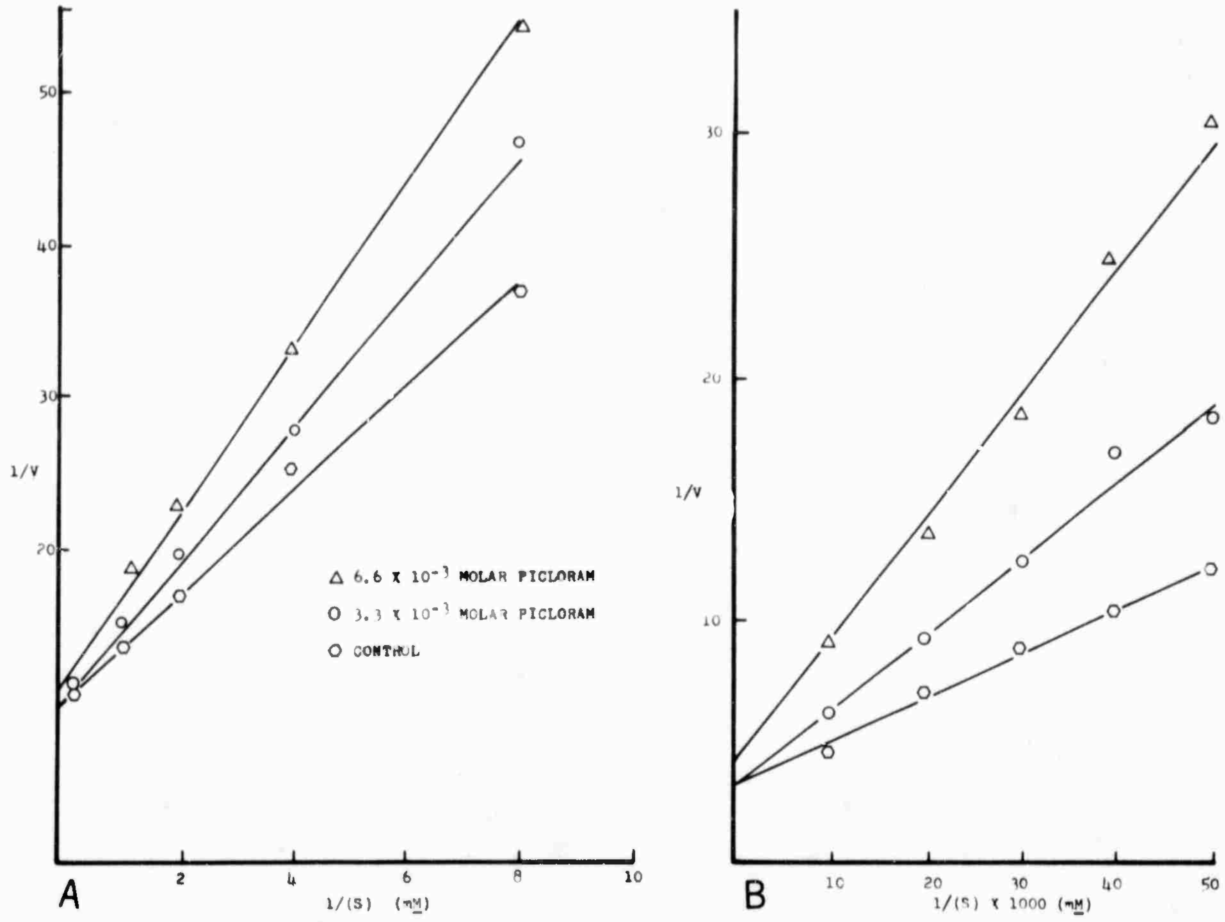

Figure 2.8.--Double reciprocal plots of substrate concentration (S) versus velocity (V) as affected by picloram when malate concentration is held near the optimum and (A) NAD and (B) NADH are varied.

of picloram and i = the inhibited fraction of activity. The hyperbolic curve obtained for picloram (fig. 2.9) was characteristic of mixed inhibition, in which an effect occurs on both the enzyme and the substrate. Similar plotting for 2,4-D yielded a different curve, suggesting that the effects of 2,4-D and picloram were not identical.

The kinetic analyses indicate that picloram and 2,4-D act at the same site and apparently both compete with NAD. Picloram, however, had another effect on the enzyme that 2,4-D lacked.

The structure of isocil was studied because it represents another group of herbicides that are biologically active. Carbonyl compounds are able to undergo a tautomeric change so that the compounds exist in both keto and enol forms. The purpose of this study was to determine the extent to which isocil undergoes this tautomeric change.

Recent developments in spectrophotometry have provided weed scientists with quick and convenient means of identifying herbicides. Infrared, ultraviolet and Raman spectra of substances, together with standard chemical tests for functional groups, permits a determination of precise chemical structure. However, if a compound exists in two or more tautomeric forms, the precise structure is difficult or impossible to determine by conventional methods.

For example, isocil could possess either of two structures (fig. 2.10). Since the only difference between the two structures is the location of a proton, nuclear magnetic resonance appeared to offer a possible solution for determining the structure of isocil. The apparatus consists of a powerful electromagnet and a sensitive radio receiver to measure the radio frequency emitted by the proton.

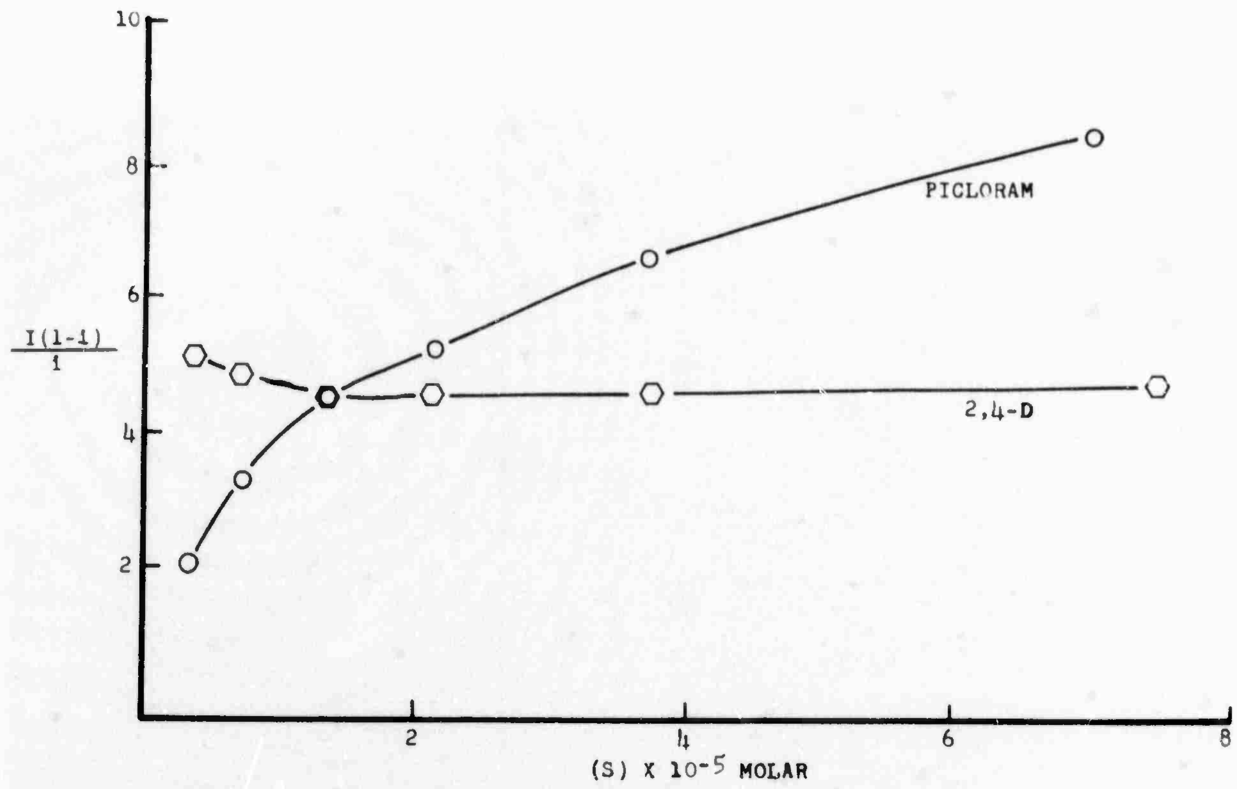

Figure 2.9.--Single curve plots of the mechanism of inhibition of picloram and 2,4-D.

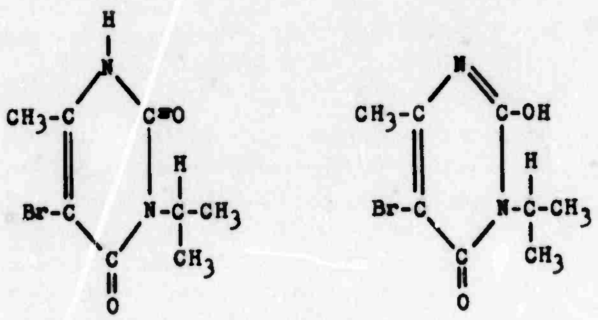

Figure 2.10.--Possible structures for isocil. Keto (left) and enol (right).

The data obtained indicate that the proton is bonded almost entirely to the nitrogen at position one rather than the oxygen at position two. If this conclusion is correct, and the N-H bond structure is the active moiety, the removal of the alkyl radical at position three could reduce the herbicidal activity. A pseudo-aromatic structure would then be possible in the enol form.

Nuclear magnetic resonance may also be of value in determining structures of other groups of herbicides, such as the substituted ureas and carbamates, where tautomeric forms are believed to exist.

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CHAPTER 3

CLIMATOLOGIC AND ECOLOGIC CHARACTERIZATION OF RESEARCH SITES IN PUERTO RICO AND TEXAS

There are numerous variables affecting the performance of herbicides. The most important variable, of course, is the vegetation itself. A given herbicide will be differentially effective for controlling grasses, herbs, and woody plants. More specifically, a given herbicide may be effective for controlling one woody species, but ineffective for controlling another. Other variables that influence herbicidal performance are the amount and frequency of rainfall, temperature, and soil type.

The information contained in this chapter will characterize the climatologic, edaphic, and vegetational features of the research sites in Puerto Rico and Texas. Such background information will aid in the interpretations of the research results that are obtained.

Puerto Rico

Topography

Puerto Rico is the easternmost and smallest of the Greater Antilles. It lies between 17°55′ N. and 18°31′ N. latitude and 65°37′ W. and 67°17′ W. longitude. It is about 109 miles long from east to west and about 40 miles from its northernmost to its southernmost tips. The overall area is a little more than 3,400 sq. mi.

Puerto Rico presents a rugged profile. A mountainous ridge, the Cordillera Central, is located in an east-west direction, slightly south of the centerline of the island. El Yunque rises to 3,448 ft. in the eastern mountains and Cerro de Punta, in the central part of the island, reaches an elevation of 4,390 ft. Since the spine of the Cordillera Central lies in the southern half of the island, the coastal plains range from 8 to 12 miles along the northern coast and 2 to 8 miles along the southern coast. There is a moderately steep rise to the peaks in the north, while in the south, the descent to the sea is rather abrupt. Topography in any portion of the mountains is rugged. Slopes up to and exceeding 45° are common.

Precipitation

The majority of Puerto Rico's rainfall is orographic in nature (7). The island lies in the path of the westerly flowing Atlantic tradewinds. Moisture-laden air from the ocean is carried inland by the tradewinds and forced to ascend over the mountains, which results in cooling and consequent precipitation. The El Yunque Mountains in the eastern part of the island are the first to cause an orographic rise and the highest rainfall is found there. The El Yunque area has an annual average of 183.51 in. Rainfall on the upper slopes of the Cordillera Central ranges from 80 to 120 in. The lowest annual averages occur along the western portion of the south coast, the lowest being 34.62 in. at Santa Rita. Thus, over a distance of only about 75 miles, there is a difference of nearly 150 in. of rainfall annually.

The effect of topography and winds upon the rainfall is well illustrated in the isohyetals (fig. 3.1). In general, the rainfall along the northern or windward coast is greater than along the southern or leeward coast. As indicated earlier, the slope of the hills to the

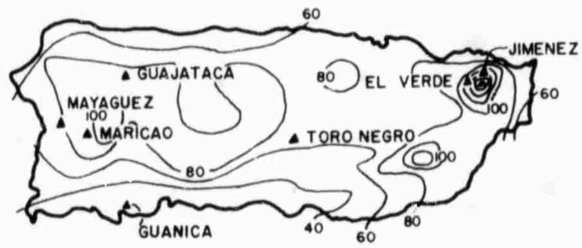

Figure 3.1.--Isohyetals and the location of research sites in Puerto Rico.

peaks is gradual in the north, while the drop to the ocean on the south is quite precipitous. This is reflected in the isohyetals where there is a rather gradual increase in the amount of rainfall on the northern slopes up to the divide. In the south, where the topographic slope is much greater, rainfall shows a sharp decrease from the ridge to the coast. The number of days with measurable rain follows the isohyetal pattern, with the largest number in areas with greatest rainfall. Once again there is a pattern of an increase from the north coast to the area of heaviest rainfall, and then a rather sharp decrease to the south coast, which has the lowest average rainfall. The average number of rainy days varies from just under 300 in the El Yunque area to less than 100 along the south coast, with 56 at Santa Rita being the lowest.

Temperature

Mean temperatures in Puerto Rico have a very small range between the warmest and coolest months. The smallest range, about 5° F., is usually found in areas near the coast; the largest range, about 7°, is found in the interior of the island. Maximum and minimum isotherms for January and July are shown in figure 3.2.

The diurnal temperature range varies with location on the island. In the areas along the northern and eastern coasts, the mean daily range is usually between 10° and 15°, with increasing values inland away from the tempering effect of the oceans. The mean diurnal range is between 15° and 20° in the southeast and more than 20° in the west and southwest. Maximum diurnal ranges of about 25° occur in the central mountains.

Extreme temperatures are unknown in Puerto Rico, but afternoon temperatures in the 90's are not unusual in coastal areas. The highest temperature ever recorded in Puerto Rico was 103° F. in 1911 at San Lorenzo in the southeastern part of the island. The coolest temperature ever recorded was 40° F. in March 1911 at Aibonito in the central mountainous portion of the island. Most of the mountainous areas have experienced temperatures in the 40's, but in the coastal areas,

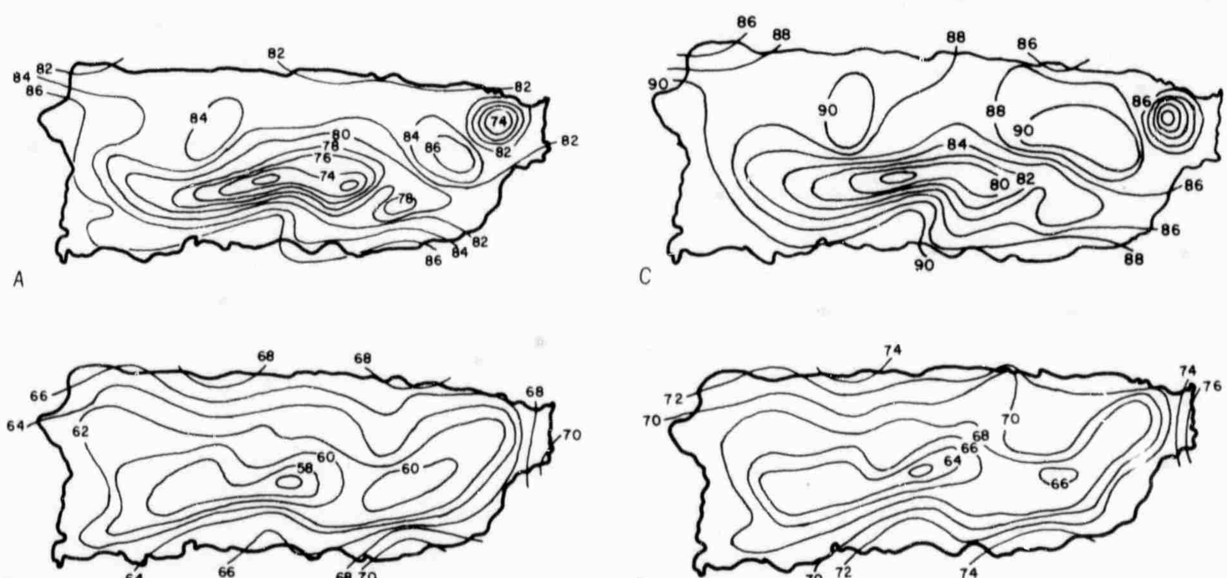

Figure 3.2.--Mean maximum and minimum isotherms in °F. January and July in Puerto Rico: A, Maximum-January; B, minimum-January; C, maximum-July; D, minimum-July.

the coolest temperatures on record are generally between 50° and 60°.

Relative Humidity

The relative humidity in the island is rather high, averaging about 80 percent over the course of the year. Generally speaking, relative humidity values of 90 percent or more during the night are not infrequent; during the day, values from 60 percent to the low 70's are predominant. Extremely low relative humidity is rare. The lowest readings are generally in the 50's.

The relatively small differences in the dewpoint temperature over the area indicate that the air mass overlying the area is quite similar with respect to moisture content throughout the year. There is also a very small diurnal change in dewpoint. At San Juan, for example, the annual average dewpoint at 2:00 a.m., 8:00 a.m., 2:00 p.m., and 8:00 p.m. is 70° F. This also appears to be true at other locations.

Vegetation

The natural vegetation of Puerto Rico has been described in a number of publications (2, 4). At the time of discovery Puerto Rico was covered with extensive and luxuriant forests. The original native vegetation has been modified drastically, however, by an ever expanding population. During settlement of the interior of the island in the 19th century, more than 99 percent of the area was deforested to varying degrees (9). No area of appreciable size escaped the strong influence of man. Today there are only a few very small areas that still have virgin forests.

Despite the drastic modifications that have resulted from cutting trees for timber and for charcoal, and the clearing of land for agricultural development, a map of the native vegetational areas (fig. 3.3) of Puerto Rico is still important. The map in figure 3.3 was taken from Little and Wadsworth (6).

The more important differences in the natural vegetation of Puerto Rico reflect variations in topography, climate, and soil. The vegetation of the coastal plains is unlike that of the steep upper slopes, and still different from the forest found on the uppermost peaks. Differences in the total amount and seasonal distribution of precipitation produce extreme differences between the forests of the eastern mountains and those of the southwest coast. Reduced moisture availability due to shallow soils, particularly in the limestone regions, is manifest in the growth of trees on such areas. The contrasts among the various vegetative types are striking because of the extreme range of conditions within short distances. Elevations range from sea

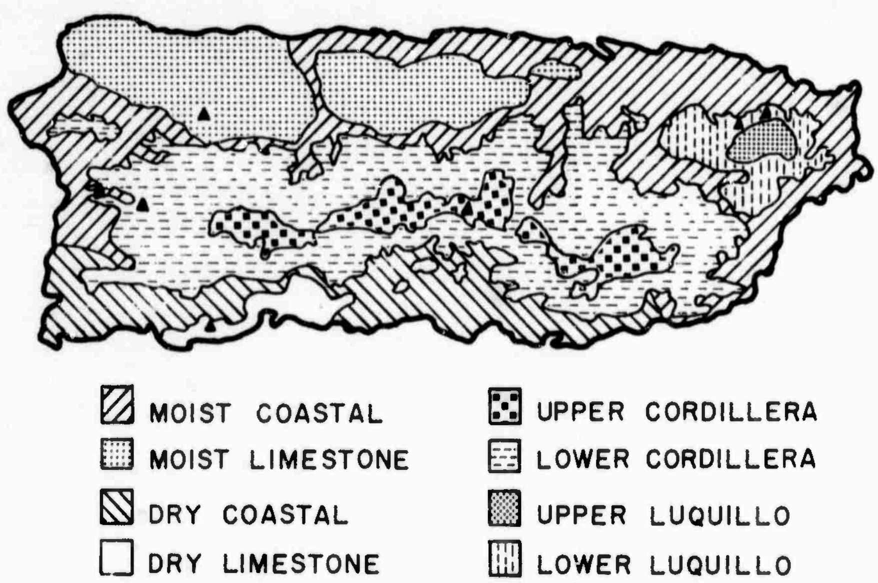

Figure 3.3.--Forest types of Puerto Rico (6).

level to 4,390 ft., precipitation from 30 to 180 in. annually, and soils from deep to very shallow and from fine clays to coarse sands.

Eight forest types are shown in the vegetational map. Not shown is a small area of littoral woodland that occurs along the windswept northern seacoast. In its native state this forest type contained good timber species such as maría, ausubo, roble, and tortugo amarillo. One of the most prominent species near the shore, uva de playa, is still commonly present today.

Mangrove is another type not shown on the map in figure 3.3. Five public forests that border the coast still contain mangroves. Mangle colorado is found in the water itself. On the adjacent area, normally subject to tidal flooding, are found mangle blanco and mangle prieto. Mangle botón occurs on the landward side of the mangrove complex.

The moist coastal forest of Puerto Rico occurs principally along the north coast, but also to some extent on the west and east coasts. The more common species include: laurel avispillo, moca, palo de pollo, espino rubial, maría, mamey, guava, tortugo amarillo, péndula, capá blanco, roble, palo de cucubano, and tintillo.

The moist limestone forest is similar to the moist coastal forest and has many of the same species. The chief differences appear to be due to the drier soils on the well-drained limestone hills and greater humidity in the protected areas between the hills, especially in the southern part of this area which is close to the central mountains. The tree species of the moist limestone forest include: palma de coyer, palma de lluvia, uvilla, moralón, canelilla, espino rubial, almácigo, cedro hembra, cedro macho, tabaiba, ceboruquillo, maga, guano, cupey, úcar, verdiseco, sanguinaria, tortugo amarillo, palo de cucubano, aquilón, and tintillo.

On the southern, dry side of Puerto Rico the more adverse moisture conditions exclude many of the tree species common on the north side. In their places grow a few other species especially adapted to such conditions. The tree species of the dry coastal forest include: calambreña, burro prieto, cóbana negra, genogeno, tachuelo, indio, guayacán, violeta, ceiba, guácima, barbasco, úcar, palo amargo, capa colorado, and péndula.

In the limestone region of the south coast, as on the north coast, excessive soil drainage accentuates the dryness of the environment to a point that some tree species cannot subsist. Others which are more hardy replace these. The trees of the dry limestone forest include: corcho bobo, burro prieto, tachuelo, guayacán, guayacán blanco, tea, almácigo, yaití, serrasuela, abeyuelo, cascarroya, sebucán, tuna de petate, úcar, sanguinaria, and alelí.

The vegetation in the mountainous areas of Puerto Rico falls into two convenient ecological provinces. The main mountain ridge, Cordillera Central, is separated geographically and ecologically from the Luquillo Mountains in the northeast part of the island. The principle reason for the difference between the two areas is that the Luquillo Mountains have more rainfall and the soils are not as well drained.

The trees of the Lower Cordillera Forest include: helecho gigante, yagrumo hembra, laurel geo, nuez moscada, icaquillo, guamá, cojoba, moca, palo de matos, tabonuco, cedro hembra, guaraguao, maricao, varital, guara, aguacatillo, rabo ratón, caracolillo, granadillo, cieneguillo, pollo, yagrumo macho, hueso blanco, capá prieto, muñeco, moral, higüerillo, and roble.

The forest of the lower slopes of the Luquillo Mountains is similar in general appearance to that of the Cordillera, but because of greater precipitation and higher humidity it is somewhat more luxuriant, and several tree species are much more common here than elsewhere. The trees of the Lower Luquillo include: helecho gigante, yagrumo hembra, guajón, laurel geo, nuez moscada, icaquillo, guamá, moca, palo de matos, tabonuco, masa, guargaguao, gaeta, maricao, palo de gallina, varital, tabaiba, guara, aguacatillo, motillo, guano, rabo ratón, granadillo, cieneguillo, ausubo, hueso blanco, muñeco, and roble.

The upper slopes of the mountains of Puerto Rico have lower temperatures and higher rainfall than the lower slopes. Consequently, the trees that are found here are distinct. The common tree species of the Upper Cordillera include: helecho gigante, palma de sierra, jagüilla, haya minga, nemocá, palo bobo, achiotillo, asuco cimarrón, negra lora, cupeíllo, jusillo, camasey peludo, and caimitillo.

In the Upper Luquillo Mountains, the forest is similar to that of the Cordillera Central, but there are also a number of species found only on the Luquillo Mountains. The common tree species of the upper Luquillo Forest include: helecho gigante, palma de sierra, laurel sabino, nemocá, achiotillo, sabinón, palo colorado, negra lora, cupeíllo, limoncillo, guayabota, jusillo, camasey peludo, caimitillo, caimitillo verde, and roble.

The best developed forests in Puerto Rico have disappeared. Cutting of the forests took place primarily in the 19th century. It eliminated tree growth from the more fertile and accessible lands. The remaining trees are located chiefly on the steep slopes, rocky mountain summits, or where excessive shallowness, dryness, or wetness of the soil precludes economic farming. Most of the forests today are those which reappeared after farming was abandoned on poor lands. Few trees exceed 12 in. in diameter and most of these are used only for fuel. These larger trees of inferior quality tend to suppress the development of younger trees of more valuable species which may be growing beneath them.

A number of introduced exotic tree species have become naturalized in the forests of the highlands. Common naturalized species of the humid forest for Puerto Rico include: pomarrosa, majagua, almendro, bucayo gigante, and tulipán africano. On the dry southwestern coast bayahonda has become naturalized. Caoba dominicana and acacia amarilla have been planted in many localities on the island.

Texas

Topography

The lowest elevation in Texas occurs along the Gulf Coast. Westward and northwestward from the Gulf Coast, elevation gradually rises to 1,000 or 2,000 ft. through Central Texas and to as high as 4,000 ft. in the western part of the Panhandle. The principal mountains of Texas are in the Trans-Pecos region where the Rocky Mountain system crosses from New Mexico to Old Mexico. The highest point is Guadalupe Peak (8,751 ft.) near El Paso. Many streams dissect the State, these flowing irregularly from the northwest to the Gulf Coast.

Precipitation

The principal sources of moisture for Texas are the Gulf of Mexico and the tropical Atlantic (1, 8). Warm and moist tropical air masses, carried by the prevailing southeasterly winds, move inland up the land slope and up the slopes of cold fronts of continental air masses. Cooling causes a loss of their moisture supply. The highest rainfall occurs in extreme east Texas with annual averages of more than 55 in. and records of more than 80 in. Precipitation decreases progressively from east to west (fig. 3.4). The isohyetals are roughly

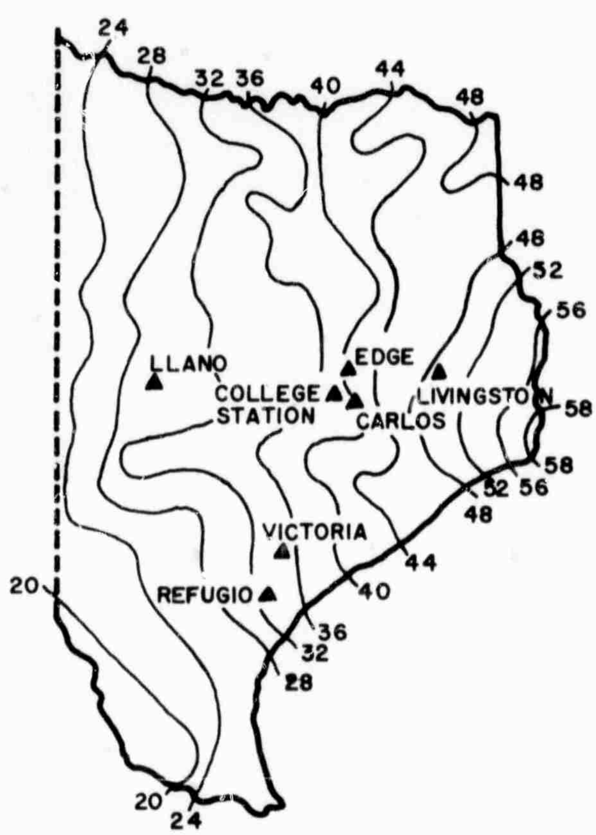

Figure 3.4.--Location of research sites in Texas and isohyetals east of the 100th meridian.

parallel and run north and south over most of the State. May has more rainfall than other months in most of the State. East Texas has a fairly uniform monthly rainfall distribution pattern with slight highs in May and December.

Temperature

Most of Texas has a continental climate characterized by rapid changes of temperature, marked extremes, and large diurnal and annual temperature ranges. Temperature drops of 40^{o} to 50^{o} F. in 12 hr. are not uncommon in the northern half of the State. The marine climate of the coastal area is characterized by comparatively uniform temperatures in all seasons with a small diurnal range. The maximum and minimum isotherms for January run roughly east and west but those of July are much less regular (fig. 3.5). The warmest part of the State is the lower Rio Grande Valley. The highest temperature recorded in Texas was 120^{o} F. at Seymour in August 1936. The coldest section is the northwestern Panhandle. The lowest tempeature recorded was -23^{o} F. at Seminole in February 1933 and at Tulia in February 1899. No part of the State is free from occasional periods of excessive heat when temperatures of 100^{o} F. or higher are recorded, nor from occasional periods of freezing temperatures. The Coastal counties and the lower Rio Grande Valley have damaging freezes only at infrequent intervals.

Relative Humidity

Relative humidity values vary considerably between winter and summer. On the whole, relative humidity in the summer ranges about 10 percent higher than in the winter. The highest relative humidity values occur in the early morning; the lowest in midafternoon. Early morning averages are about 90 percent along the coast and about 75 percent in the interior. Early evening averages are about 70 percent along the coast and 50 percent inland.

Vegetation

Many different systems of classification have been proposed to facilitate the analysis of plant communities in Texas. They range from the broad, theoretical treatment of Weaver and Clements (10) to the practical, highly specific range condition method used by the Soil Conservation Service (3). Neither the broad nor the highly specific systems are particularly helpful in this report. The system to be used is a compromise based on topographic, climatic, and edaphic factors, as well as broad plant community similarities (5).

The descriptive titles given on the vegetational map (fig. 3.6) refer to the dominant vegetation of the area or to a topographic feature that has arisen through geologic evolution. In this report the descriptive titles are used to locate the vegetational areas, but specific experimental sites will be more closely defined by referring to a specific woody species or an association of woody species.

Piney Woods.--The Piney Woods in East Texas occur on gently rolling to hilly forested land. An annual rainfall of 40 to 55 in. is fairly uniformly distributed throughout the year.

Mature forested areas have an association of loblolly, shortleaf, longleaf, and slash pines with hardwoods such as oaks, hickory, and maple. The ratio of pine to hardwood decreases with distance westward from the Texas-Louisiana border.

In areas where the oak-pine has been cut, a dense, complex association of forbs and brush soon occupy the site. Yaupon, oaks, ash, sassafras, and elm are common constituents of the brush complex.

Gulf Prairie.--The Gulf Prairie occurs on a nearly level, slowly drained plain, dissected by streams flowing into the Gulf. Annual rainfall averages between 32 and 36 in. The rainfall is fairly uniformly distributed throughout the year with slight highs in September and late spring.

Most of the area has been invaded by trees and brush. One of the research sites in the Gulf Prairie contained a dense stand of live oak. The other research site had an association of huisache-mesquite.

Post Oak Savannah.--The Post Oak Savannah lies in a narrow belt east of the Piney Woods and the Gulf Prairie. Annual rainfall ranges from about 35 to 45 in. The high rainfall month is usually May or June.

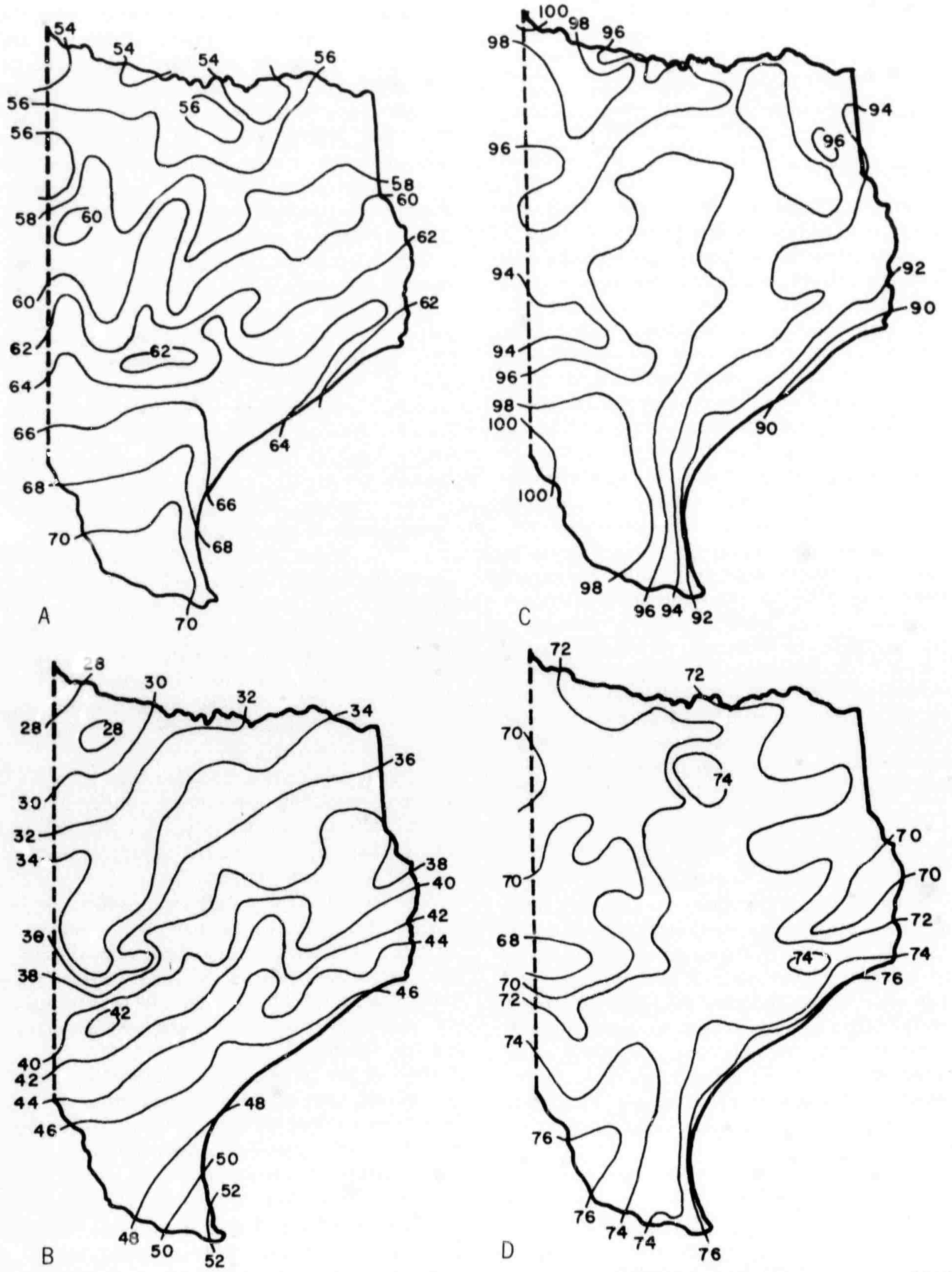

Figure 3.5.--Mean maximum and minimum isotherms in °F. for January and July in Texas east of the 100th meridian: A, Maximum-January; B, minimum-January; C, maximum-July; D, minimum-July.

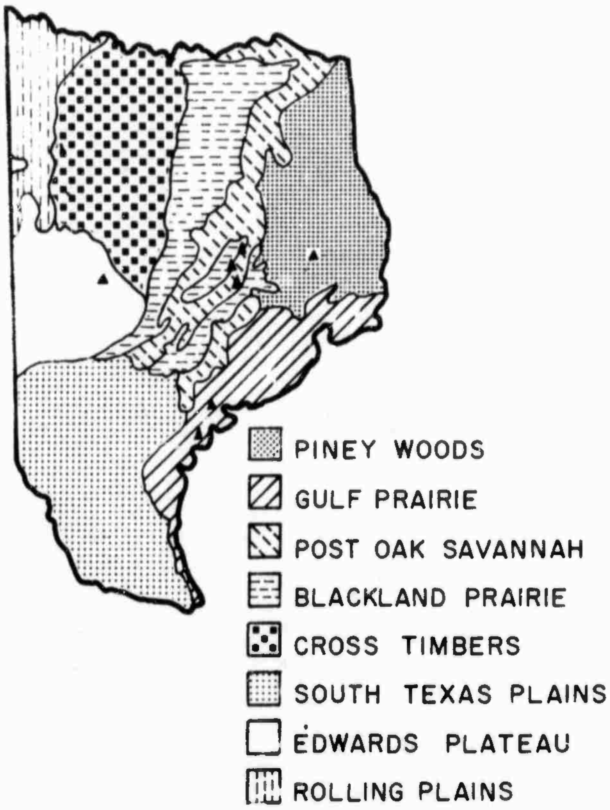

Figure 3.6.--Vegetational areas of Texas east of the 100th meridian.

Post oak is the predominant woody species, but blackjack oak and winged elm are also common. Yaupon is a common understory species.

Edwards Plateau.--The Edwards Plateau in West-Central Texas has an average annual rainfall ranging from about 15 in. in the west to 35 in. in the east. Average annual rainfall at the Llano research site is about 30 in. A typical rainfall pattern shows a seasonal high in May and June, and again in September. Droughts occur in the area frequently.

Whitebrush was the principal woody species of interest in the Edwards Plateau. Whitebrush is commonly associated with mesquite, Texas persimmon, and various species of cactus.

We did not have research sites in the Blackland Prairie, Cross Timbers and Prairies, South Texas Plains, and Rolling Plains. The location of research sites was governed primarily by the presence of woody species that were difficult to control with phenoxy herbicides, and secondarily by availability of land that contained those woody species.

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CHAPTER 4

HERBICIDAL EVALUATIONS IN A WOODY PLANT NURSERY

Preparation of the irrigated, woody plant nursery at the Texas A & M Research Annex was started in April 1963. The nursery was developed primarily to evaluate new chemicals for their defoliating and herbicidal properties on woody plants. The nursery approach to herbicidal evaluation is not new. It is being used at industrial and research institutions, but few of the species grown in the Southwestern United States are included in such nurseries.

There are three factors which made chemical evaluation in a woody plant nursery worthwhile. First, when several species of woody plants are grown at one location, chemicals can be evaluated quickly with a minimum expenditure of human and material resources. Second, growing the plants under irrigated conditions permits maximum growth and eliminates drought as a factor in the responses of the plants to chemical treatments. Third, the ages and developmental histories of plants are known and can be evaluated for their influence on the responses of plants to chemical treatments.

There are several problems that should be considered when using a nursery. Woody plants may not respond similarly to defoliants and herbicides when grown under cultivation as when growing in wild stands, but this is usually not an important factor for primary evaluation of chemicals. Some woody plant species are not easily propagated under cultivated conditions. Considerable time, certain specialized equipment, irrigation facilities, and personnel with experience in propagating plants are needed to establish these species in a nursery. Time is needed to grow woody plants to a suitable size and stage of development for herbicidal evaluation studies. Lastly, certain cultural practices such as fertilization, irrigation, and weed control must be developed and carried out if the nursery is to be properly maintained. The woody plant nursery was also used for certain ecological and physiological studies. Dates of flowering, seed set, and other phenological phenomena were of importance to this project, because they are important factors influencing the response of plants to defoliants and herbicides. In addition, the nursery was used as a source of plant materials for laboratory studies (figures 4.1 and 4.2).

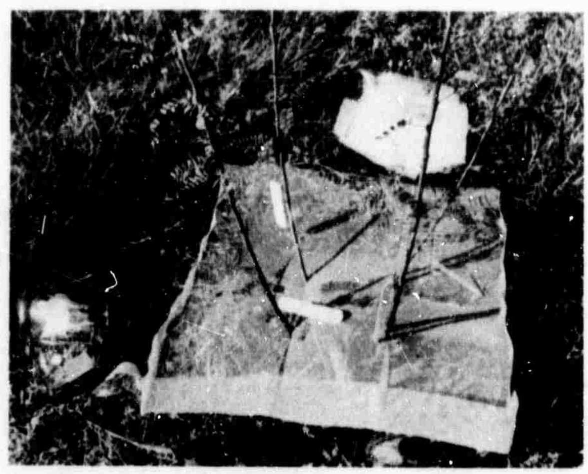

Figure 4.1.--Mesquite seedlings and equipment needed for field study of absorption and translocation of herbicides. Window screen was used to prevent loss of defoliated leaves after treatment.

Figure 4.2.--Leaves and stems of a 3-year old mesquite plant tagged for study of chemical absorption and translocation.

The land assigned for establishment of the woody plant nursery is contained in seven blocks between the ramp and runways of a former airbase located at the Texas A & M Research Annex. The usable acreage is approximately 75 acres. The soil type is primarily Erving clay loam.

Methods of Establishing Nursery Plants

Four methods were used to establish woody plants in the nursery: (1) Transplanting vegetative tissues from plants grown in wild stands, (2) transplanting seedlings grown from seed in the greenhouse, (3) transplanting seedlings obtained from commercial nurseries, and (4) direct seeding. Because the propagation of these species was inadequately understood, several techniques were tested to determine the one most satisfactory for a given species. Large numbers of seeds and vegetative tissues were needed for nursery plantings, so most of the planting operations had to be mechanized. A device was constructed to thresh seed of mesquite and huisache from pods. The device (fig. 4.3) consists of a barley pearling machine with modified threshing screen and cylinder (fig. 4.4) and a two-screen, wind cleaner. With this device, 1 bushel of mesquite pods can be threshed in 1.5 man-hours, as contrasted with 160 man-hours to cut the seed from the pods with a scalpel.

Water for irrigation was drawn from two deep wells. Both wells were equipped with electric motors and pumps. They were connected to the irrigation system through a gate valve and adapter. Water was carried to the nursery blocks in 6-in. extruded aluminum pipes. Two methods of irrigation were used. Furrow irrigation was used on level areas with gentle slope. Water was carried to the furrows in 5-in. aluminum pipes and discharged into the furrows through gated pipes. On rough areas water was distributed over the land through 3-in. pipes equipped with 24-inch risers and low capacity agricultural sprinklers.

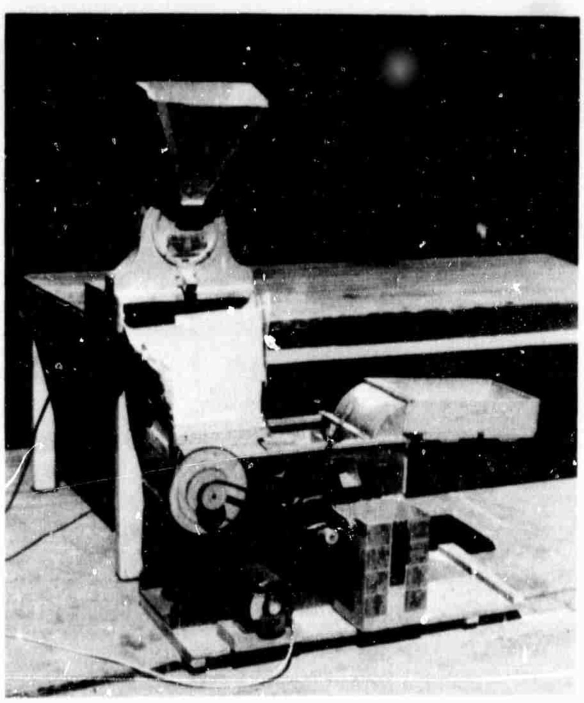

Figure 4.3.--Threshing device, consisting of modified barley pearling machine and two-screen air cleaner assembled for threshing and cleaning mesquite seed.

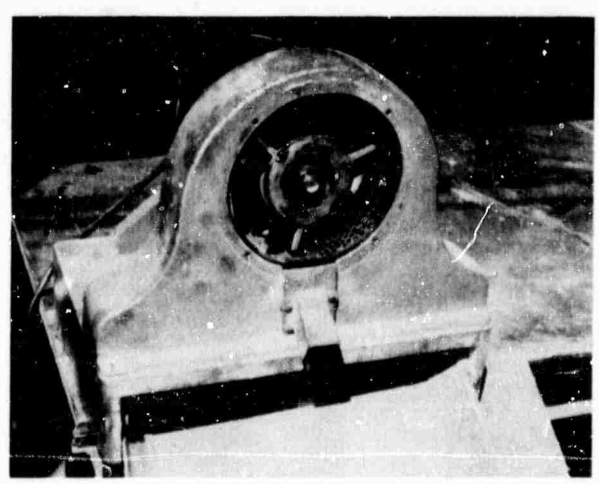

Figure 4.4.--Barley huller with cover removed showing threshing cylinder with attached steel bars and threshing screen.

Species Established in Nursery

A wide variety of woody plant families was included in the nursery so that the maximum amount of information from evaluation studies could be obtained. The species selected for establishment in the nursery are listed in table 4.1. Only mesquite, live oak, whitebrush, winged elm, and Macartney rose were available for establishment in the nursery in 1963. The other species were added in subsequent years as seed or plant materials became available.

Greenbriar.--Greenbriar plants were established in the nursery from rhizomes dug from wild stands. The tissues were cut into 3- to 4-in. segments and planted at 2-ft. intervals in rows. Successful transplantings were made in later winter. It was necessary to plant the greenbriar tissues immediately after digging because poor stands resulted when tiessues were exposed to the atmosphere for prolonged periods of time.

Huisache.--Huisache was established by direct seeding and by transplanting seedlings grown from seed in the greenhouse. Both methods were entirely satisfactory, but the direct seeding method was most economical. Huisache seed requires scarification before it will germinate. Seedlings attained heights of approximately 7 ft. at the end of the first growing season in the woody plant nursery.

Live Oak.--Live oak seedlings were established from acorns planted directly in the nursery, from seedlings grown in the greenhouse from acorns, and from seedlings purchased from a commercial nursery. The most economical and satisfactory method was direct seeding. Acorns harvested in late fall and planted immediately gave excellent stands and little labor was needed for planting. Growing seedlings in the greenhouse and transplanting in the nursery were successful, but required space in the greenhouse and labor for care of the plants. Satisfactory stands were also established from seedlings purchased from commercial nurseries, but this method was the most expensive. Seedlings established by any of the three methods attained a height of approximately 3 ft. at the end of the first growing season (fig. 4.5).

Figure 4.5.--Live oak seedlings planted June 1963; photographed December 1963.

TABLE 4.1.--Woody species established in nursery

Common name	Scientific name	
	Family	Species
Greenbriar	Liliaceae	Smilax bona-nox
Huiaache	Leguminosae	Acacia farneaiana
Live oak	Fagaceae	Quercus virginiana
Loblolly pine	Pinaceae	Pinus taeda
Macartney rose	Rosaceae	Roaa bracteata
Mesquite	Leguminosae	Proacpis juliflora
Whitebrush	Verbenaceae	Aloysia lycioidea
Winged elm	Ulmaceae	Ulmus alata
Yaupon	Aquifoliaceae	Ilex vomitoria

Loblolly Pine.--Seedlings of loblolly pine were purchased from the Texas Forest Service and transplanted into the nursery. December and January were the preferred months to transplant. Loblolly pine did not grow well in the heavy soils of the nursery, but good stands were obtained in the better drained soils. Seedlings died in heavy soils that received excessive amounts of runoff water from the concrete runways, but grew rapidly enough to permit treatment 1 yr. after transplanting in well-drained sites.

Macartney Rose.--Macartney rose was established in the nursery from corwns of plants dug from wild stands. Excellent stands were obtained when transplanting was done in December, January, or February during cool weather (fig. 4.6). However, transplanting could be done at any time of the year, and the first plantings were made in June and July 1963. Frequent irrigation was necessary during the 2 mo. immediately after transplanting, and even then only 34 percent of the plants became established (fig. 4.7). Because of the rapid growth of this species, seedlings could be used for chemical evaluation studies at the end of the first growing season.

Figure 4.6.--Macartney rose planted January 1965; photographed July 1966. Note abundant hedge-type growth. Weeds in foreground are primarily nutsedge and bermudagrass.

Figure 4.7.--Macartney rose planted July 1963; photographed July 1965. Note open areas where plants were not established and large hedges developed by plants which were established in this planting.

Mesquite.--Mesquite was established in the woody plant nursery by methods identical to those described for huisache. Mesquite did not grow as rapidly as huisache, but irrigated seedlings grew to heights of 4 ft. in one growing season (fig. 4.8). The root system of 14-month-old mesquite seedlings was found to penetrate into the soil to a depth of over 5 ft. and to spread laterally 4 ft. (fig. 4.9).

Figure 4.8.--Mesquite seedlings planted June 1963; photographed December 1963.

Figure 4.9.--Excavation of root system of 14-month-old mesquite seedling. Roots penetrated to a depth of over 5 ft. and extended laterally for a distance of 4 ft.

Whitebrush.--Whitebrush was established from crowns of plants dug from wild stands and from seedlings grown from seed in the greenhouse. The latter method was more successful. Whitebrush seed will not germinate at high temperatures, but does germinate readily at temperatures below 75° F. Because no seed of this species was available in 1963, crowns were dug from wild stands at Llano and transplanted into the nursery. Approximately 65 percent of the plants were established (fig. 4.10). However, subsequent transplantings of crowns from wild stands were not successful. After methods were developed for the germination of seed and for growing plants in the

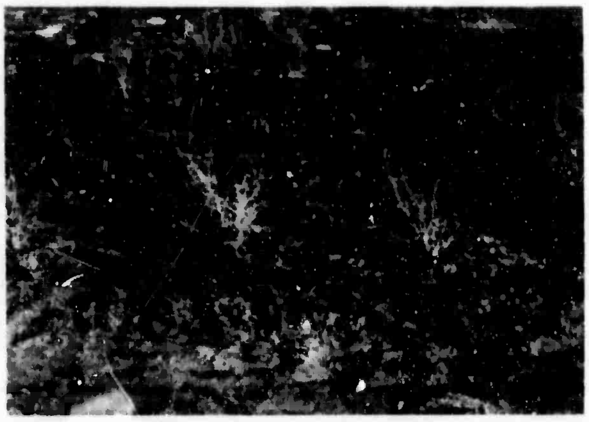

Figure 4.10.--Whitebrush plants established from crowns dug from wild stands at Llano July 1963; photographed December 1963. Approximately 65 percent of the crowns were established in this planting.

greenhouse, all plantings were made with seedlings grown in the greenhouse. Seedlings of this species attained heights of approximately 5 ft. during the first growing season (fig. 4.11).

Figure 4.11.--Whitebrush seedlings established from seedlings grown in greenhouse, planted May 1964; photographed October 1964. Over 95 percent of the plants were established in this planting.

Winged Elm.--Winged elm seedlings were established in early May by transplanting seedlings grown from seed in the greenhouse. The small size of the seed precluded establishment of uniform stands of this species in the nursery by direct seeding. However, if better methods of seedbed preparation and other agronomic practices are developed, it may be possible to seed this species directly in the future. Sufficient size of winged elm seedlings were attained to permit chemical evaluations the season following establishment (fig. 4.12).

Figure 4.12.--Winged elm seedlings planted June 1963; photographed May 1964.

Yaupon.--Yaupon was established in the nursery from seedlings purchased from commercial nurseries in 1964 and 1965. This method was not satisfactory. In 1964, although seedlings were in excellent condition at the time of planting and weather conditions were favorable for establishment of plants, less than 5 percent of the transplants were established. In 1965, conditions for establishment of the plants were favorable and approximately 15 percent of the plants were established. Yaupon seed has a 2-yr. dormancy period, and no method has yet been found to break this dormancy.

Evaluation of Herbicides and Herbicide Combinations

New compounds became available each year and mixtures of certain compounds that showed promise as defoliants or herbicides in greenhouse evaluations were re-evaluated in the woody plant nursery. In 1964, only a limited number of suitable plants were available for evaluation studies. In 1965 and 1966 sufficient plants of each of the species were available to permit evaluation of all new chemicals or combinations of chemicals that were considered worthy of evaluation.

Tests in 1964

An experiment was conducted in the nursery in 1964 to evaluate five herbicides for their defoliation and herbicidal properties on winged elm and to compare the responses of winged elm plants in the nursery with those in wild stands. The herbicides and rates of each were (1) the 2-ethylhexyl ester of 2,4,5-T at 2 lb. per acre, (2) the potassium salt of picloram at 1 lb. per acre, (3) the dimethylamine salt of dicamba at 4 lb. per acre, (4) paraquat at 4 lb. per acre, and (5) the wettable powder of bromacil at 5 lb. per acre. All the herbicides were diluted with water and sprayed on the foliage of winged elm on May 13, 1964.

Paraquat killed the leaves most rapidly, followed by 2,4,5-T and dicamba (table 4.2). Picloram and bromacil were not effective defoliants at 7 days. In general, the initial responses of plants in the nursery were comparable to those of plants in wild stands. Nursery plants that had not been killed refoliated in October, but field plants were still defoliated due to drought and possibly herbicide-induced dormancy. Approximately 1 yr. after treatment, plants in the nursery had either refoliated or were in advanced stages of deterioration. The only changes from evaluations made the previous fall were small increases of the number of plants killed on plots treated with picloram, 2,4,5-T, paraquat, and dicamba, but a decrease on plots treated with bromacil. In wild stands there were marked reductions in the control obtained from all chemicals. Final evaluations made in the spring of 1965 showed good agreement between nursery and wild stands of winged elm treated with 2,4,5-T, paraquat, and dicamba. A much higher percentage of control of nursery plants than of wild stands was obtained with picloram and bromacil. This is probably due to the activity of these two herbicides in the soil. Irrigation water during the months following treatment would have leached these herbicides into the soil.

From these data, it is evident that winged elm plants in the nursery give responses similar to those in wild stands when the herbicides were applied to the foliage. Both the initial response and the refoliation of plants in the nursery was more rapid than that of plants in wild stands.

TABLE 4.2.--Percentage of defoliation and kill of winged elm obtained from foliar treatments with five herbicides on May 13, 1964

Herbicide	Defoliation, 7 days		Kill			
			Fall 1964		Spring 1965	
	nursery	wild	nursery	wild	nursery	wild
	Percent					
Picloram	16	10	58	95	69	10
2,4,5-T	45	53	7	100	12	13
Dicamba	38	33	27	70	38	15
Paraquat	93	23	14	85	25	10
Bromacil	13	0	100	98	88	5

Tests in 1965

Herbicides were applied as foliage sprays to Macartney rose, mesquite, greenbriar, live oak, and winged elm plants in 1965. Rates of 2 and 8 lb. per acre were arbitrarily selected for all herbicides on all species. Amizine, pyriclor, and picloram were applied to mesquite and live oak on June 17, 1965, but treatments then had to be discounted because of high wind. The remaining treatments were applied to all species on June 24 and 29, 1965. Evaluations of leaves killed were made 1 week after treatment and of plants killed in June 1966.

Macartney Rose.--Picloram and mixtures containing picloram were the most effective herbicides applied to Macartney rose; however, DSMA (both Ansar 160 and 529), potassium azide, pyriclor and paraquat; amitrole were mcre effective defoliants than picloram (table 4.3).

Live Oak.--Picloram was the most effective herbicide applied to live oak (table 4.3). The addition of pyriclor or amitrole did not enhance its activity. Despite the high percentages of leaves killed by most herbicides, none gave satisfactory defoliation. The most effective was DSMA (Ansar 160). Bromacil and paraquat:amitrole also gave relatively high defoliation after 4 wk.

Mesquite.--Picloram alone and in combinations with other chemicals was the most effective herbicide and the most persistent defoliant applied to mesquite. DSMA, sodium and potassium azides, and paraquat caused rapid defoliation of mesquite but regrowth occurred within 4 wk. on all plants treated with these compounds. Both rates of picloram and the highest rates of picloram:amitrole and Ansar 529 were the only herbicides that killed a significant number of plants.

Greenbriar.--DSMA, sodium and potassium azides, and paraquat:amitrole killed the leaves of greenbriar quite rapidly, but no treatment prevented regrowth for as long as 4 wk. No rapid defoliant was found for greenbriar in this experiment. The picloram:amitrole combination at 8 lb. per acre killed all greenbriar and warrants further investigation.

Winged Elm.--Picloram alone and in combination with pyriclor or amitrole was the most effective and persistent herbicide on winged elm. Bromacil at 8 lb. per acre killed all winged elm plants to which it was applied. Defoliation was most rapid after treatment with DSMA at 2 lb. per acre, but refoliation occurred within 2 wk. on all plots.

Tests in 1966

Two new chemicals and several new formulations of picloram and phenoxy herbicides were available for evaluation in the nursery

TABLE 4.3.--Percentage of leaves and plants killed of five species treated with thirteen herbicides in June 1965[1]

Herbicide	Rate	Macartney rose	Live oak	Mesquite	Greenbriar	Winged elm
	Lb. per acre	- - - - - - - -	- - - - - - - -	Percent	- - - - - - - -	- - - - - - - -
DSMA (Ansar 160)	2	70/0	60/0	90/7	67/13	90/0
	8	95/5	90/0	97/10	88/7	95/0
DSMA (Ansar 529)	2	70/0	56/0	53/57	67/10	50/0
	8	90/20	80/0	95/87	92/27	90/0
Sodium azide	15	60/0	80/0	72/0	40/3	70/0
	20	80/5	60/0	90/0	40/3	80/0
	25	90/5	80/0	90/0	80/13	60/0
Potassium azide	15	80/0	70/0	80/0	90/0	80/0
	20	60/0	80/0	85/0	40/0	60/0
	25	90/0	70/0	90/0	60/0	60/0
Bromacil	2	10/0	67/67	20/0	8/0	80/30
	8	60/5	80/100	67/0	20/13	80/100
Amizine	2	10/20	10/0	20/0	15/33	20/0
	8	20/40	23/0	27/0	13/0	10/0
Pyriclor	2	80/0	27/0	82/3	30/2	50/0
	8	98/5	43/13	67/19	43/13	70/0
Paraquat:amitrole (1:1)	2	95/10	57/13	92/0	50/37	60/0
	8	98/20	73/20	98/12	92/10	80/0
Piclcram	2	40/100	87/93	100/97	3/17	95/100
	8	50/100	100/100	100/100	16/90	100/100
Pyriclor:picloram (2:1)	2	70/100	43/0	99/23	20/2	40/20
	8	98/100	75/100	100/63	43/3	96/100
Picloram:amitrole (1:1)	2	40/100	43/7	96/60	5/43	95/100
	8	70/100	93/100	99/100	10/100	98/100

[1] The figure to the left of the slash mark represents the percentage of leaves killed 1 week after treatment; that to the right, percentage plants killed 11 months after treatment.

in 1966. On June 15, greenbriar plants were treated with the 2-ethylhexyl ester of 2,4,5-T, picloram, amitrole, picloram:amitrole, Dupont 767, and NIA 11092 at rates of 4 and 8 lb. per acre. Picloram:amitrole was applied only at 8 lb. per acre. Live oak was treated with the ester of 2,4,5-T, picloram, Dupont 767, NIA 11092, and bromacil at rates of 4 and 8 lb. per acre on June 10. Loblolly pine was treated with the ester of 2,4,5-T, picloram, Dupont 767, NIA 11092, bromacil, and paraquat at rates of 2 and 4 lb. per acre on June 15, 1966. During the period of July 19 to 22, 1966, acid, amine and ester formulations of 2,4,5-T were applied to winged elm, live oak, and mesquite. The acid and amine were experimental formulations that were emulsifiable in water or in oil-water carriers. The 2-ethylhexyl ester of 2,4,5-T was applied as a standard for comparison. Similar formulations of 2,4-D were applied to Macartney rose. We applied the compounds in water and in diesel oil-water (1:10 vol. per vol.) at a rate equivalent to 20 gal. per acre. The treatments applied in June were evaluated 2 weeks and 3 mo. after treatment; the treatments applied in July were evaluated 6 wk. after treatment.

Greenbriar.--The ester of 2,4,5-T was the most effective herbicide applied (table 4.4). NIA 11092 caused necrosis slowly in leaf tissues but the number of dead leaves and stems increased with time after treatment. The picloram:amitrole combination, which gave good control of greenbriar in 1965, gave only fair control in 1966. Final evaluations of control will be needed in 1967 before effectiveness of this treatment can be determined.

Live Oak.--Picloram killed the highest percentage of leaves and bromacil the next highest (table 4.4). The emulsifiable acid and amine and ester formulations of 2,4,5-T did not differ in their toxicities to live oak (table 4.5).

Loblolly Pine.--As in 1965, paraquat was the most toxic compound applied to loblolly pine (table 4.4).

Winged Elm.--None of the 2,4,5-T formulations killed all leaves of winged elm (table 4.5). However, considering the conditions at the time of treatment and the lateness

TABLE 4.4.--Percentage of leaves killed on three plant species

Herbicide	Rate	Greenbriar		Live oak		Loblolly pine[1]	
		2 wk.	3 mo.	2 wk.	3 mo.	2 wk.	3 mo.
	Lb. per acre	- - - - - - - - -	- - -	-Percent-	- - -	- - -	- - -
Ester of 2,4,5-T	4	72	99	82	80	8	27
	8	90	99	99	94	13	20
Picloram	4	32	60	100	100	40	45
	8	22	78	100	100	65	63
Amitrole	4	25	47	--	--	--	--
	8	10	60	--	--	--	--
Picloram:amitrole (1:1)	8	50	70	--	--	--	--
Dupont 767	4	5	23	65	38	33	42
	8	5	42	60	91	--	--
NIA 11092	4	20	70	75	94	27	33
	8	25	88	78	63	20	30
Bromacil	4	--	--	79	92	60	55
	8	--	-	86	94	27	50
Paraquat	2	--	--	--	--	98	99
	4	--	--	--	--	100	99
Check	0	0	5	0	13	20	13

[1] Herbicides applied to loblolly pine at 2 and 4 lb. per acre.

TABLE 4.5.--Percentage of dead leaves on four species treated with three herbicides applied in water and oil-water carrier

Herbicide	Rate	Species and kind of diluent[1]							
		Winged elm		Live oak		Mesquite		Macartney rose	
		W	O-W	W	O-W	W	O-W	W	O-W
	Lb. per acre	Percent							
2,4,5-T:									
Acid	1	62	83	53	60	99	100	--	--
	2	87	57	95	80	100	100	--	--
Amine	1	75	92	73	73	93	100	--	--
	2	90	95	92	94	98	100	--	--
Ester	1	87	43	60	60	97	100	--	--
	2	60	93	87	72	98	98	--	--
2,4-D:									
Acid	1	--	--	--	--	--	--	53	63
	2	--	--	--	--	--	--	80	90
Amine	1	--	--	--	--	--	--	70	78
	2	--	--	--	--	--	--	83	81
Ester	1	-	--	--	--	--	--	28	53
	2	--	--	--	--	--	--	63	86

[1] W = water; O-W = oil-water.

of the season, the results were surprisingly good.

Mesquite.--All treatments killed 93 percent or more of the leaves (table 4.5) and little regrowth was evident on any of the plants in September.

Macartney Rose.--When applied in the oil carriers, herbicides generally killed more of the leaves than when applied in water, but there were no substantial differences in results obtained with the different formulations of 2,4-D (table 4.5).

Live oak and huisache.--Picloram has been highly toxic to both live oak and huisache, and combinations of picloram and 2,4,5-T controlled these species in preliminary field experiments. Because amine salts of 2,4,5-T are less expensive and generally kill leaves of plants slower than does the ester of 2,4,5-T, a test was initiated in 1966 to compare the salts and esters of 2,4,5-T with a salt of picloram.

We applied the potassium salt of picloram, triethylamine salt of 2,4,5-T, and 2-ethylhexyl ester of 2,4,5-T at rates of 2 and 4 lb. per acre to live oak on June 10 and to huisache on June 9. Also, we applied combinations of picloram plus ester of 2,4,5-T and picloram plus amine salts of 2,4,5-T at 1 plus 1 and 2 plus 2 lb. per acre. Five plants were treated in each plot and four plots were treated with each treatment. We evaluated the percentage of dead leaves on each plot 2 wk. and 3 mo. after treatment.

The combination of ester of 2,4,5-T and picloram provided the highest initial kills of live oak leaves. All treatments except the ester of 2,4,5-T and 2-lb. per acre rate of the amine salt of 2,4,5-T killed 90 percent or more of the leaves after 3 mo. (table 4.6).

All treatments killed 90 percent or more of the leaves of huisache 2 wk. after treatment. However, refoliation occurred 3 mo. after treatment on most of the plots treated with amine or ester of 2,4,5-T alone.

Leaves of live oak were killed more rapidly with the combinations of picloram and 2,4,5-T than with either chemical applied alone at the lower rate. Suppression of regrowth was as effective as with equivalent rates of picloram. For huisache there was no advantage derived from mixing the two herbicides.

TABLE 4.6.--Percent dead leaves on live oak and huisache plants treated with picloram, amine and ester formulations of 2,4,5-T and combinations of picloram and 2,4,5-T

Herbicide	Rate	Live oak		Huisache	
		2 wk.	3 mo.	2 wk.	3 mo.
	Lb. per acre	Percent			
Picloram	2	54	99	100	100
	4	97	99	100	100
Ester of 2,4,5-T	2	88	68	98	92
	4	90	69	99	97
Amine of 2,4,5-T	2	89	79	92	52
	4	95	93	95	60
Picloram:ester of 2,4,5-T (1:1)	2	95	100	100	99
	4	98	100	100	100
Picloram:amine of 2,4,5-T (1:1)	2	93	99	100	100
	4	96	99	100	99
Check	0	10	8	0	0

Influence of Volume and Type of Carrier on Herbicidal Effectiveness

The volume and type of carrier in which herbicidal sprays are applied has been shown to influence the effectiveness of herbicidal sprays. Adequate volume is necessary to insure distribution of the herbicide over the plants to be treated. However, high volumes are often expensive to apply and may reduce effectiveness of the herbicide because the capacity of the plants to retain the spray is exceeded.

Foliage sprays for the control of woody plants often contain both diesel oil and water. For example, the recommended carriers for treatments on mesquite, post oak, and blackjack oak are diesel oil-water emulsions. Diesel oil is less volatile than water and, because it evaporates more slowly, oil-spray droplets are more likely to reach the plant in a hot, dry climate. However, the phytotoxic properties of diesel oil are well known. It has been suggested that diesel oil reduces the effectiveness of 2,4,5-T treatments because of the rapidity with which it kills leaves, thus, immobilizing the transport system of the leaves. If this is true, such a phenomenon should be most readily observed in an easily defoliated species such as mesquite. On the other hand, the lipoidal nature of diesel oil may cause it to act as a penetrating agent through its solvent action on the cuticular material of hard-to-kill leaves, such as live oak. Three tests were conducted in which the influence of volume and type of carrier were evaluated.

In the first test, mesquite, live oak, and winged elm plants were treated with the 2-ethylhexyl ester of 2,4,5-T; Macartney rose was treated with the 2-ethylhexyl ester of 2,4-D; and whitebrush was treated with the butoxyethyl ester of MCPA on June 16, 1965. Rates of application were one-half lb. per acre on mesquite; 1 lb. per acre on whitebrush; and 2 lb. per acre on live oak, winged elm, and Macartney rose.

All herbicides were applied in an oil-water carrier (1:3) at volumes equivalent to 4, 20, and 100 gal. per acre with a three-nozzle hand boom attached to a 3-gal. compressed air sprayer. Size of the Teejet nozzle tips used for the 4, 20, and 100 vol. were 800067, 8001, and 8015, respectively. Evaluations of percentages of leaves killed were made 1, 2, and 4 wk. after treatment, and evaluations of stems killed were made 5 and 13 mo. after treatment.

Treatments applied at 20 gal. per acre were generally more effective than those applied at 4 and 100 (table 4.7), but the differences were not great. The largest differences in stems killed were found in mesquite and winged elm; the smallest differences in whitebrush.

The second test was initiated to determine if water, diesel oil, or a combination of the

TABLE 4.7.--Percentage of leaves and stems killed of five species treated with herbicides in three volumes of an oil-water carrier

Species and herbicide	Rate	Volume	Leaves			Stems	
			1 wk.	2 wk.	4 wk.	5 mo.	13 mo.
	Lb. per acre	Gal. per acre	- - - - - - - -	- - -	Percent	- - -	- - - - - - - -
Mesquite:							
2,4,5-T	1/2	4	70	85	92	--	60
		20	64	95	100	--	95
		100	46	77	96	--	70
Live oak:							
2,4,5-T	2	4	34	81	82	63	44
		20	62	92	94	74	67
		100	34	76	82	74	64
Winged elm:							
2,4,5-T	2	4	38	66	66	69	38
		20	82	95	97	82	83
		100	66	82	85	70	59
Macartney rose:							
2,4-D	2	4	60	85	75	32	27
		20	68	98	96	60	46
		100	70	94	93	60	34
Whitebrush:							
MCPA	1	4	78	83	79	81	55
		20	97	97	91	82	60
		100	92	95	90	82	62

two was the most effective carrier of 2,4,5-T when applied for the defoliation and control of mesquite and live oak.

Fifteen-month old mesquite and live oak plants were treated with the 2-ethylhexyl ester of 2,4,5-T at rates of one-half and 1 lb. per acre to mesquite and at rates of 1 and 2 lb. per acre to live oak. Water, diesel oil, and diesel oil-water emulsions at ratios of 1:3, 1:9, and 1:18 were used as carriers. Diesel oil was applied without herbicide. All treatments were applied at volumes equivalent to 20 gal. per acre on June 9, 1966, with a tractor-mounted, compressed air sprayer. Evaluations of dead leaves on the plants were made 3 wk. and 3 mo. after treatment.

The evaluations are summarized in Table 4.8. Both water and diesel oil were effective carriers of 2,4,5-T when applied to mesquite. The diesel oil-water carriers were less effective than either water or diesel oil at the one-half lb. per acre herbicide rate. Emulsification of the ester of 2,4,5-T was dependent upon the emulsifiers in the herbicide concentrate. The spray emulsions were shaken during the spraying operation but the emulsion stability may not have been sufficient to permit transport of the emulsion from the spray tank to the plant surfaces. That may account for the reduced effectiveness of the diesel oil-water carrier.

Water sprays killed more leaves of live oak than diesel oil sprays at the 1 lb. per acre rate, when evaluated after 3 wk., but after 3 mo. there was little difference.

In the third test, ester of 2,4,5-T, amine salts of 2,4,5-T, and amine salts of 2,4-D were applied to live oak, mesquite, whitebrush, and Macartney rose on August 6, 1964. Mesquite and whitebrush plants were defoliated in approximately 7 days, but whitebrush began refoliation within 28 days after treatment (table 4.9). Live oak and Macartney rose leaves were killed slowly. After 28 days the percentage of leaves killed was nearly equal for all species, ranging from 61 to 98 percent on live oak, 90 to 100 percent on mesquite, 55 to 96 percent on whitebrush, and 94 to 99 percent on Macartney rose.

All treatments were evaluated for control on May 7, 1965, (table 4.9). 2,4-D was more toxic to Macartney rose than 2,4,5-T. Applying 2,4,5-T in diesel oil increased phytotoxicity to Macartney rose slightly, but other additives and carriers did not.

Amine salts of 2,4-D were most toxic to whitebrush, but all treatments were relatively ineffective.

TABLE 4.8.--Percentage of dead leaves on mesquite and live oak plants after application of 2,4,5-T in water, diesel oil, and diesel oil-water carrier[1]

Species	Rate	Carrier				
		Water	Diesel oil	Diesel oil:water ratio		
				1:3	1:9	1:18
	Lb. per acre	- - - - -	- - - - -	Percent	- - - - -	- - - - -
3-week evaluation:						
Mesquite	1/2	96	99	18	38	74
	1	100	100	100	100	99
	0	--	18	--	--	--
	0	8	--	--	--	[illegible]
Live oak	1	66	16	43	45	61
	2	85	90	40	79	8[illegible]
	0	--	10	--	--	--
	0	9	--	--	--	--
3-month evaluation:						
Mesquite	1/2	96	98	15	18	69
	1	91	100	100	98	99
	0	--	15	--	--	--
	0	3	--	--	--	--
Live oak	1	48	42	12	41	40
	2	66	90	42	62	58
	0	--	40	--	--	--
	0	8	--	--	--	--

[1] Species not present on plots where no percentage figure is shown.

TABLE 4.9.--Percentage of leaves killed, defoliation, and control of four woody plant species treated with 2,4,5-T or 2,4-D in various carriers[1]

Treatment	Rate	Leaves killed/defoliation[2]				Plants killed[3]			
		Live oak	Mesquite	White-brush	Macartney rose	Live oak	Mesquite	White-brush	Macartney rose
	Lb. per acre	- - - - -	- - - - -	- - - - -	- - - - -	Percent	- - - - -	- - - - -	- - - - -
2-ethylhexyl ester of 2,4,5-T	2	63/23	94/91	55/55	97/18	17	88	6	55
2-ethylhexyl ester of 2,4-5-T + NH_4SCN	2 + 1/10	82/13	94/92	80/80	99/28	11	69	6	54
Dimethyl Tridecyl amine of 2,4-D	2	88/7	95/91	96/96	99/20	17	50	58	88
Ethomeen T/15 amine of 2,4-D	2	61/16	90/88	--	92/20	33	--	--	85
Triethylamine of 2,4,5-T	2	80/28	98/96	90/90	93/24	33	92	35	20
Triethylamine of 2,4,5-T + 5 percent propylene glycol	2	79/22	96/96	--	99/29	50	100	--	60
Triethylamine of 2,4,5-T + 5 percent glycerin	2	93/8	97/94	--	99/14	25	86	--	70
2-ethylhexyl ester of 2,4,5-T + 5 percent C^{56} in diesel oil	2	97/13	94/91	--	94/19	53	86	--	29
Triethylamine of 2,4,5-T + 5 percent hexaflouroacetone	2	90/22	94/92	68/68	97/19	31	77	0	42
2-ethylhexyl ester of 2,4,5-T in diesel oil	2	98/8	100/96	62/62	96/50	58	100	33	76

[1] All treatments applied August 6, 1964, at a volume of 30 gal. per acre.
[2] Evaluations made 28 days after treatment. The figure to the left of the slash mark represents leaves killed; that to the right represents defoliation.
[3] Evaluations made May 7, 1965.

Considering that treatments were applied late in the spraying season, good control of mesquite was achieved with several 2,4,5-T treatments. The esters of 2,4,5-T applied in diesel oil gave the most effective control. The 2,4,5-T amine gave good control of mesquite, which is unusual for late season applications.

Control of live oak was poor and percentages of control achieved by all treatments were statistically similar.

Influence of Additives on Effectiveness of Defoliants and Herbicides

Previous studies have shown that the phytotoxicity of certain herbicides to woody plants is enhanced by the addition of certain additives, that is, emulsifiers, sticker-spreaders, and, in some cases, inorganic salts. Three tests were conducted in the nursery to evaluate some of the more promising additives to determine if they would increase the rapidity of defoliation or increase the duration of control of woody plants. Two tests were conducted in which the addition of ammonium thiocyanate to phenoxy herbicides was evaluated and one test was conducted in which different concentration of DMSO and a commercial surfactant were evaluated.

In the first test, oil-water emulsions (1:3 vol. per vol.) containing low volatile esters were applied at a volume of 20 gal. per acre to woody plants in the nursery on June 16, 1965. The 2-ethylhexyl ester of 2,4,5-T was applied to mesquite, winged elm, and live oak at rates of one-half, 2, and 2 lb. per acre, respectively. The butoxyethyl ester of MCPA was applied to whitebrush at a rate of 1 lb. per acre. The 2-ethylhexyl ester of 2,4-D was applied to Macartney rose at 2 lb. per acre. Ammonium thiocyanate was added to one-half of the treatments applied to each species at a rate equivalent to 1 part ammonium thiocyanate to 20 parts of the herbicide (weight per weight). All treatments were applied with a 3-nozzle hand boom attached to a 3-gal. compressed air sprayer. Each treatment was replicated five times. Evaluations of leaves killed were made 1, 2, and 4 wk. after treatment, and evaluations of stems killed were made 12 mo. after treatment.

Addition of ammonium thiocyanate did not influence the rapidity or number of leaves killed on any species (table 4.10). Likewise, the addition of ammonium thiocyanate caused no substantial differences in stems killed in mesquite, live oak, winged elm, or whitebrush. However, ammonium thiocyanate increased the control of Macartney rose by 20 percent when final evaluations were made 12 mo. after treatment.

In the second test, dimethylamine salts of 2,4-D and 2-ethylhexyl ester of 2,4-D were applied to Macartney rose plants at 2 lb. per

TABLE 4.10.--Percentage of leaves and stems killed of five species treated with and without ammonium thiocyanate added to oil-water emulsions of substituted phenoxy herbicides

Species and herbicide	Rate	Leaves			Stems
		1 wk.	2 wk.	4 wk.	12 mo.
	Lb. per acre	Percent			
Mesquite:					
2,4,5-T	1/2	70	95	100	--
2,4,5-T + NH_4SCN	1/2	70	94	98	--
Live oak:					
2,4,5-T	2	69	91	95	35
2,4,5-T + NH_4SCN	2	66	90	96	40
Macartney rose:					
2,4-D	2	68	96	96	30
2,4-D + NH_4SCN	2	76	97	96	50
Winged elm:					
2,4,5-T	2	70	90	93	40
2,4,5-T + NH_4SCN	2	68	85	92	40
Whitebrush:					
MCPA	1	99	100	95	70
MCPA + NH_4SCN	1	99	100	99	80

acre, alone and in combination with 0.1 lb. per acre of ammonium thiocyanate, on May 9 and 31 and June 29, 1966. The amine treatments were applied in water and the ester treatments in diesel oil-water (1:3) at volumes of 20 gal. per acre with the tractor-mounted sprayer. The percentage of dead leaves on plants in each plot were estimated 2 weeks after treatment and in early September.

Evaluations of dead leaves on the plants 2 weeks after treatment and in early September are summarized in table 4.11. As was true in previous studies, there was no substantial difference in percentage of leaves killed when ammonium thiocyanate was added to the 2,4-D sprays. Regrowth on the plants will be evaluated on all plots in early spring and summer of 1967, and final evaluations will be made in 1967 or 1968.

The third test was conducted to compare the effects of different concentrations of DMSO and X-77 on the defoliant and herbicidal properties of 2,4-D, 2,4,5-T, picloram, and paraquat.

Fifteen-month old live oak and Macartney rose plants were used for all treatments. We treated live oak plants with the potassium salt of picloram, 2-ethylhexyl ester of 2,4,5-T, and paraquat each at 1 and 2 lb. per acre. Macartney rose plants were treated with the potassium salt of picloram at one-fourth and one-half lb. per acre, with the dimethylamine salt of 2,4-D and paraquat each at 1 and 2 lb. per acre. DMSO or X-77 was added to the aqueous herbicidal sprays at rates of 0, 0.1, 1.0, and 10 percent (vol. per vol.) of the spray volume. All treatments were applied at volumes equivalent to 20 gal. per acre with a tractor-mounted, compressed air sprayer. Live oak was treated on June 22 and 27, 1966, and Macartney rose on June 28 and 29. Evaluations of the percentage of dead leaves on each plant were made at 2 wk. and at 2 mo. after treatment. Plants killed by the treatments will be determined in 1967.

Generally, sprays containing X-77 were more effective than sprays containing DMSO on Macartney rose (table 4.12). As concentration of surfactant increased, initial percentage of leaves killed increased slightly. Two months after treatment refoliation was very much in evidence on the plants treated with paraquat, but only small amounts of refoliation occurred on plants treated with picloram and 2,4-D.

There were no consistent differences in leaves killed 2 wk. after treatment between plants treated with the two surfactants or between plants treated at the different surfactant concentrations (table 4.13). The percentage of dead leaves on live oak plants did not change between the 2-wk. and the 2-mo. evaluations except on the plants treated with 2,4,5-T plus X-77. For the latter, refoliation was evident after 2 months.

TABLE 4.11.--Percentage of dead leaves on Macartney rose plants treated with 2,4-D and 2,4-D plus ammonium thiocyanate on three dates

Herbicide	Rate	Date of application					
		May 9		May 31		June 29	
		2 wk.	17 wk.	2 wk.	15 wk.	2 wk.	10 wk.
	Lb. per acre	Percent					
Amine of 2,4-D	2	93	96	87	73	65	35
Amine of 2,4-D + NH_4SCN	2 + 0.1	90	98	91	68	76	50
Ester of 2,4-D	2	95	97	28	8	70	43
Ester of 2,4-D + NH_4SCN	2 + 0.1	91	98	34	10	75	43
Check	0	0	0	0	0	0	0

TABLE 4.12.--Percentage of dead leaves on Macartney rose plants treated with herbicides plus X-77 or DMSO at four concentrations

Herbicide	Rate	Surfactant concentration	Defoliation at specified times after treatment			
			X-77		DMSO	
			2 wk.	2 mo.	2 wk.	2 mo.
	Lb. per acre	Percent	Percent			
Picloram	1/4	0.0	35	33	--	--
		0.1	35	38	35	35
		1.0	75	68	38	33
		10.0	81	71	50	30
	1/2	0.0	73	60	--	--
		0.1	63	68	55	63
		1.0	78	83	69	71
		10.0	88	98	65	73
2,4-D	1	0.0	84	87	--	--
		0.1	76	75	65	61
		1.0	84	92	84	70
		10.0	87	84	83	71
	2	0.0	65	66	--	--
		0.1	55	45	48	28
		1.0	70	48	43	30
		10.0	78	53	73	65
Paraquat	1	0.0	84	43	--	--
		0.1	84	40	85	40
		1.0	86	43	84	38
		10.0	85	50	83	38
	2	0.0	79	23	--	--
		0.1	83	43	68	30
		1.0	85	40	81	25
		10.0	86	43	78	40

TABLE 4.13.--Percentage of dead leaves on live oak plants treated with herbicides plus X-77 or DMSO at four concentrations

Herbicide	Rate	Surfactant concentration	Defoliation at specified times after treatment			
			X-77		DMSO	
			2 wk.	2 mo.	2 wk.	2 mo.
	Lb. per acre	Percent	Percent			
Picloram	1	0.0	90	90	89	93
		0.1	91	96	88	89
		1.0	94	100	93	97
		10.0	97	100	95	97
	2	0.0	91	96	91	96
		0.1	88	95	95	96
		1.0	94	99	95	66
		10.0	99	100	86	97
2,4,5-T	1	0.0	73	43	81	58
		0.1	63	45	65	50
		1.0	53	33	76	53
		10.0	78	53	79	88
	2	0.0	73	43	83	81
		0.1	63	45	83	88
		1.0	53	33	84	94
		10.0	78	53	80	75
Paraquat	1	0.0	79	88	79	70
		0.1	84	76	70	65
		1.0	76	70	80	68
		10.0	89	88	86	66
	2	0.0	88	83	86	86
		0.1	89	91	89	94
		1.0	89	90	89	90
		10.0	89	92	86	91

Evaluation of Herbicides at Different Rates and Dates of Application

Three tests were conducted in which chemicals were evaluated at different rates and dates of application on woody plants in the nursery. In the first test, picloram was applied to mesquite, whitebrush, Macartney rose and winged elm; MCPA to whitebrush; and 2,4,5-T to mesquite and Macartney rose. Treatments were applied on May 13, June 3, and July 24, 1964. All herbicides were applied at rates of one-fourth, 1, and 4 lb. per acre at each date. The percentage of defoliation and leaves killed was evaluated 7 days after treatment and final evaluation of plants killed was made on May 7, 1965.

Neither picloram nor 2,4,5-T was effective for defoliating Macartney rose, and picloram was not effective for defoliating winged elm (table 4.14). Both picloram and 2,4,5-T were relatively ineffective as defoliants on mesquite, but 2,4,5-T did provide 50 percent defoliation in 7 days at the 4-lb. per acre rate. MCPA was a more effective defoliant of whitebrush than was picloram.

It is evident that picloram was more effective than 2,4,5-T in controlling Macartney rose on all treatment dates and at all rates. The 1/4-lb-per-acre rate of picloram did not give satisfactory control of Macartney rose on any of the three dates. One pound per acre of picloram killed 75 percent or more on all dates, and 4 lb. per acre killed all of the Macartney rose on all dates.

Picloram did not control winged elm at the 1/4- and 1-lb-per-acre rates, but the 4-lb-per-acre rate gave satisfactory control. In general, 2,4,5-T gave slightly better control of mesquite than did picloram on all dates. Complete control of mesquire was obtained

TABLE 4.14.--Percentage of defoliation and kill of four woody plant species treated with picloram, 2,4,5-T, or MCPA at three rates on three dates[1]

Species and chemical	Treated 5-13-64			Treated 6-3-64			Treated 7-24-64		
	1/4 lb. per acre	1 lb. per acre	4 lb. per acre	1/4 lb. per acre	1 lb. per acre	4 lb. per acre	1/4 lb. per acre	1 lb. per acre	4 lb. per acre
	Percent								
Macartney rose:									
Picloram	0/10	0/100	0/100	0/6	0/75	0/100	0/2	0/95	1/100
2,4,5-T	0/5	0/40	0/78	0/0	0/2	0/79	0/0	0/4	0/86
Winged Elm:									
Picloram	0/0	0/56	5/100	0/0	1/69	4/94	4/0	9/34	5/100
Mesquite:									
Picloram	50/19	29/75	21/100	26/6	10/33	16/100	2/12	20/38	16/88
2,4,5-T	18/50	16/88	35/100	46/19	29/56	44/64	9/6	11/86	12/100
Whitebrush:									
Picloram	0/0	6/19	15/92	0/0	5/12	19/77	10/0	12/0	44/22
MCPA	54/0	25/25	75/36	64/0	90/25	100/71	39/12	76/6	95/54

[1] The figure to the left of the slash mark represents the percentage of leavee defoliated after 7 days; that to the right represents the percentage kill after 1 yr.

with both chemicals at the 4 lb. per acre rate in May.

Neither picloram nor MCPA gave satisfactory control of whitebrush at 1/4- and 1-lb.per-acre rates. Picloram, applied at 4 lb. per acre on May 13, 1964, killed more whitebrush plants than any other treatment in this experiment. Percentage control from picloram treatments decreased at later dates of application. Picloram was apparently more toxic to whitebrush than MCPA, but date of application seemed to be critical. Early treatment dates should be evaluated.

The second test was conducted because results of field evaluations and preliminary studies in the woody plant nursery in 1964 indicated the need for a more critical evaluation of the rates and dates of application of the more effective herbicides and certain mixtures of herbicides on woody plants. Not only would data from such a study be valuable in the formulation of control practices for individual species, but it should also be of value in understanding the periodicity of susceptibility to chemicals in other woody plants. Sufficient numbers of year-old plants of several woody species were available in the spring of 1965 to initiate such a study. We evaluated the defoliant and herbicidal properties of five chemicals and three combinations of chemicals at selected rates and dates of application.

The compounds evaluated were those considered to be most promising for the particular species, so not all herbicides were applied to all species. The chemicals used were 2-ethylhexyl ester of 2,4,5-T, potassium salt of picloram, paraquat, 80 percent wettable powder of bromacil, and dimethylamine salt of dicamba. Three rates of each chemical were applied to each species but the rates were varied depending upon species susceptibility. All treatments were applied in water at a rate of 20 gal. per acre. Evaluations of leaves killed and defoliation were made 1 wk. after treatment and in the fall of 1965. Only the evaluation of leaves killed is reported because they were correlated with and slightly higher than most of the defoliation values. The percentage of kill was evaluated in June 1966.

Mesquite

Treatments with 2,4,5-T resulted in slowest leaf killing on all dates of application (table 4.15). Date of application of 2,4,5-T did not cause large differences in numbers of stems killed. Picloram killed leaves rapidly and was relatively effective in preventing refoliation of mesquite on all dates. However, all plots treated in April showed some refoliation by late July. Picloram applied in June was more effective for killing stems than were applications in April and July. Paraquat alone and in combination with 2,4,5-T or picloram killed mesquite leaves rapidly at all rates and

TABLE 4.15.--Percentage of meaquite leavea and atems killed by spraying with 15 treatmenta on five dates

Herbicide	Rate	Treatment dates														
		April 16, 1965			April 30, 1965			June 8, 1965			June 30, 1965			July 20, 1965		
		1 wk.	5½ mo.	14[1] mo.	1 wk.	5½ mo.	13½[1] mo.	1 wk.	17 wk.	12[1] mo.	1 wk.	13 wk.	11½[1] mo.	1 wk.	11 wk.	11[1] mo.
	Lb. per acre	- - - - - -	- - - - - -	- - - - - -	- - - - - -	- - - - - -	- - - - - -	- - - - - -	Percent	- - - - - -	- - - - - -	- - - - - -	- - - - - -	- - - - - -	- - - - - -	- - - - - -
2,4,5-T	1/2	70	43	23	57	68	50	75	48	38	68	78	60	48	88	50
	1	72	66	44	71	68	36	84	73	42	82	65	45	58	90	58
	2	58	37	20	81	68	55	84	91	75	84	91	75	70	97	75
Picloram	1/2	82	51	29	91	65	48	96	85	75	91	79	46	91	75	48
	1	100	50	33	98	90	55	99	93	82	91	91	78	94	85	68
	2	100	46	40	99	87	84	100	98	95	96	95	95	98	95	84
Paraquat	1/2	100	30	25	83	57	16	94	38	12	79	30	13	88	43	18
	1	100	61	40	92	43	17	99	45	34	92	40	13	86	40	3
	2	100	75	43	97	43	28	100	68	43	95	50	13	96	55	27
Paraquat: 2,4,5-T (1:1)	1/2	100	45	33	98	45	12	97	40	20	95	40	18	95	38	20
	1	100	58	28	100	45	16	99	43	22	97	43	18	99	45	18
	2	100	58	45	100	48	18	98	63	35	98	65	35	100	61	35
Paraquat: picloram (1:1)	1/2	100	65	38	98	48	12	97	50	25	76	48	20	94	50	18
	1	100	45	33	98	50	28	99	66	32	96	53	15	96	48	25
	2	100	71	40	99	50	20	100	81	48	100	70	33	99	73	40

[1] Evaluationa of stems killed made in June 1966.

TABLE 4.16.--Percentage of leavea and stems of live oak killed after apraying on three dates

Treatment date and herbicide	Rate	Leavea		Stems	
		1 wk.	4 wk.	16 wk.	14 mo.
	Lb. per acre	- - - - - -	- - Percent - -	- - - - - -	- - - - - -
April 16, 1965:					
2,4,5-T	2	68	20	--	5
	4	89	35	--	20
Picloram	2	80	58	--	20
	4	65	95	--	65
Bromacil:paraquat (1:1)	4	100	35	--	30
	8	99	71	--	45
June 8, 1965:					
2,4,5-T	2	75	--	60	40
	4	75	--	75	55
Picloram	2	94	--	99	75
	4	98	--	100	100
Paraquat	2	84	--	78	30
	4	97	--	96	75
Bromacil:paraquat (1:1)	4	97	--	93	63
	8	99	--	100	95
September 8, 1965:					
2,4,5-T	1	65	90	--	30
	2	63	93	--	38
	4	73	92	--	60
Picloram	1	63	88	--	60
	2	88	97	--	88
	4	93	100	--	100
Paraquat	1	38	65	--	40
	2	70	86	--	65
	4	88	91	--	89
Dicamba	1	30	48	--	20
	2	70	84	--	35
	4	78	90	--	80
Bromacil:paraquat (1:1)	4	88	97	--	94
	8	96	99	--	100

dates. When paraquat was applied in combination with picloram or 2,4,5-T, there was more rapid refoliation than when picloram or 2,4,5-T was applied alone. No treatment killed all mesquite plants.

Live Oak

Results of treatments applied to live oak on April 16, June 8, and September 8, 1965, are summarized in Table 4.16. leaf killing was slow with all treatments except those containing paraquat. Picloram and bromacil:paraquat killed leaves rapidly and prevented refoliation of live oak when applied in June and September.

The treatments applied on April 16, 1965 were relatively ineffective for killing live oak, but the 4-lb.-per-acre rate of picloram applied in June and September 1965 killed all live oak plants. Bromacil:paraquat killed 90 and 100 percent of the stems when treatments were made in June and September, respectively.

Loblolly Pine

No treatment gave rapid leaf kill of loblolly pine on April 16 (table 4.17). The most rapid acting treatment was paraquat at 4 lb. per acre, which killed 80 percent of the leaves 1 wk. after treatment. Treatments applied June 8, when air temperatures were higher, generally

TABLE 4.17.--Percentage of leaves and stems of loblolly pine killed after spraying on three dates

Treatment date and herbicide	Rate	Leaves		Stems	
		1 wk.	4 wk.	16 wk.	13 mo.
	Lb. per acre	Percent			
April 16, 1965:					
2,4,5-T	1	10	25	--	15
	2	22	38	--	40
	4	18	38	--	50
Picloram	1	18	40	--	20
	2	10	45	--	55
	4	18	95	--	98
Paraquat	1	72	78	--	80
	2	72	73	--	63
	4	80	80	--	67
Dicamba	1	8	48	--	10
	2	18	67	--	35
	4	12	60	--	55
June 8, 1965:					
2,4,5-T	1	25	--	35	33
	2	12	--	38	20
	4	16	--	79	65
Picloram	1	21	--	63	45
	2	22	--	95	95
	4	35	--	98	100
Paraquat	1	98	--	100	100
	2	98	--	100	100
	4	100	--	100	100
Dicamba	1	50	--	81	85
	2	52	--	91	85
	4	50	--	98	100
September 3, 1965:					
2,4,5-T	1	16	38	--	0
	2	20	43	--	15
	4	20	53	--	20
Picloram	1	21	23	--	10
	2	18	50	--	50
	4	19	70	--	85
Paraquat	1	38	75	--	25
	2	64	86	--	55
	4	75	93	--	90
Dicamba	1	8	25	--	0
	2	21	28	--	25
	4	11	60	--	65

killed more leaves than treatments made on the earlier date. Paraquat killed loblolly pine needles rapidly at all three rates. The other three compounds were slow acting.

All compounds were most effective when applied in June. Paraquat gave complete control at all rates in June. Picloram at 4 lb. per acre also killed all stems. The influence of date of application on paraquat activity was striking and is worthy of further investigation.

Greenbriar

Evaluations of treatments applied to greenbriar plants on four dates are summarized in table 4.18. Because chemical control of greenbriar had been unsuccessful, relatively high rates of all five chemicals were applied. No chemical was effective for killing greenbriar. Paraquat killed the tops rapidly, but regrowth occurred within 8 wk. Eight pounds of picloram applied on June 30 gave 61 percent control after 10 mo.

Winged Elm

Evaluations of picloram, 2,4,5-T and paraquat treatments applied to winged elm on April 25, June 8, and June 30, 1965, are summarized in table 4.19. Picloram was extremely effective in killing the leaves of winged elm, especially at the early dates. Paraquat and 2,4,5-T were less effective.

The third test was conducted to compare the phytotoxicities of 2,4-D, 2,4,5-T, and picloram at several rates and dates of application to Macartney rose, mesquite, and winged elm. These compounds are generally the most effective defoliants and herbicides on woody plants.

Macartney rose plants, 15 mo. old, were treated with potassium salt of picloram, dimethylamine salt of 2,4-D, and with a 1:3 combination of picloarm:2,4-D at rates of one-half, 1, and 2 lb. per acre. Mesquite plants, 15 mo. old, were treated with potassium salt of picloram, 2-ethylhexyl ester of 2,4,5-T, triethylamine salt of 2,4,5-T, 1:1 mixture of

TABLE 4.18.--Percentage of greenbriar leaves killed from treatments on four dates

Herbicide	Rate	Treatment dates											
		April 16, 1965			April 30, 1965			June 8, 1965			June 30, 1965		
		1 wk.	6 mo.	13 mo.	1 wk.	$5\frac{1}{2}$ mo.	$12\frac{1}{2}$ mo.	1 wk.	5 mo.	11 mo.	1 wk.	15 wk.	$10\frac{1}{2}$ mo.
	Lb. per acre	Percent											
2,4,5-T	2	30	23	0	10	17	0	12	23	7	8	30	5
	4	20	18	0	20	25	10	22	78	0	12	48	8
	8	50	25	8	25	17	30	30	50	8	28	53	28
Picloram	2	2	20	25	8	30	0	4	45	0	5	55	5
	4	18	35	5	8	28	0	11	63	3	14	65	8
	8	20	50	3	25	50	25	25	86	10	12	89	61
Paraquat	2	90	15	0	81	23	25	82	25	25	42	35	8
	4	92	15	0	95	27	3	98	23	5	75	33	12
	8	95	18	0	86	28	5	99	20	3	85	40	18
Bromacil	2	12	14	0	8	17	0	26	29	0	14	28	2
	4	5	18	0	3	28	0	18	25	0	5	45	0
	8	30	30	0	3	23	0	30	30	3	9	75	7
Dicamba	2	10	20	0	10	25	0	15	33	0	11	40	0
	4	30	25	25	6	20	0	14	40	25	18	50	8
	8	28	28	0	16	30	0	45	62	5	32	65	10

TABLE 4.19.--Percentage of winged elm leaves killed after treatment on three dates

Herbicide	Rate	Treatment dates								
		April 25, 1965			June 8, 1965			June 30, 1965		
		1 wk.	5½ mo.	13 mo.	1 wk.	18 wk.	11½ mo.	1 wk.	15 wk.	11 mo.
	Lb. per acre	Percent								
2,4,5-T	1	30	0	10	55	20	12	25	23	5
	2	32	0	15	50	35	45	48	35	0
	4	58	0	65	88	95	75	52	53	15
Picloram	1	48	100	100	78	91	70	35	81	40
	2	92	100	100	92	100	100	48	98	80
	4	92	100	100	92	100	100	65	100	100
Paraquat	1	75	0	20	65	8	10	35	20	0
	2	88	0	10	74	15	12	52	5	0
	4	95	0	10	86	28	35	68	28	0

TABLE 4.20.--Percentage of dead leaves on Macartney rose plants treated with picloram, 2,4-D, and picloram:2,4-D combinations at three rates and four dates

Herbicide	Rate	Treatment dates							
		April 15, 1965		May 9, 1965		May 19, 1965		May 31, 1965	
		4 wk.	20 wk.	2 wk.	20 wk.	4 wk.	20 wk.	3 wk.	18 wk.
	Lb. per acre	Percent							
Picloram	1/2	99	98	93	100	83	88	89	90
	1	100	100	90	99	99	99	93	100
	2	100	100	88	100	100	100	96	100
2,4-D, Amine salt	1/2	79	52	81	74	[1] 9	[1] 3	75	53
	1	85	48	87	90	88	81	87	63
	2	97	95	90	99	99	97	95	88
Picloram:2,4-D (1:3)	1/2	98	99	78	60	95	85	75	58
	1	99	99	95	95	99	99	93	91
	2	100	100	97	100	100	100	97	99

[1] Low value due to error in application.

picloram:amine salt of 2,4,5-T, and 1:1 mixture of picloram:ester of 2,4,5-T at one-half, 1, and 2 lb. per acre. Winged elm plants, 12 mo. old, were treated with potassium salt of picloram, 2-ethylhexylesters of 2,4,5-T, and a 1:1 mixture of picloram:2,4,5-T of 1, 2, and 3 lb. per acre. Treatments were applied in water at 20 gal. per acre with 0.5 percent (vol. per vol.) commercial surfactant (X-77) added. The tractor-mounted, compressed air sprayer was used to apply all treatments. Evaluations of the percentage of dead leaves on plants in each plot were made between 2 or 4 wk. after treatment and in September 1966. Effectiveness of the treatments in killing the plants will be determined in 1967.

Picloram was more effective than 2,4-D in killing leaves at all rates on April 15 and May 9, but differences were small when plants were treated on May 19 and 31 (table 4.20).

TABLE 4.21.--Percentage of dead leaves on mesquite plants treated with picloram, amine, and ester formulations of 2,4,5-T, and picloram:2,4,5-T at three rates on four dates

Herbicide	Rate	Treatment Dates						
		May 10, 1965		May 31, 1965		June 29, 1965		July 22, 1965
		2 wk.	4 mo.	4 wk.	3 mo.	2 wk.	2 mo.	2 mo.
	Lb. per acre	Percent						
Picloram	1/2	96	70	89	95	81	95	98
	1	100	95	95	95	85	99	100
	2	100	97	99	99	96	98	100
2,4,5-T ester	1/2	83	74	70	74	85	97	93
	1	95	63	87	65	88	99	99
	2	99	75	95	90	91	100	100
2,4,5-T amine	1/2	79	75	92	66	85	97	97
	1	99	83	98	98	91	98	100
	2	99	83	89	94	97	99	100
Picloram:2,4,5-T ester (1:1)	1/2	98	83	99	98	84	99	99
	1	100	93	100	96	92	100	98
	2	100	100	99	96	96	99	100
Picloram:2,4,5-T amine (1:1)	1/2	97	73	92	93	88	96	100
	1	99	83	89	93	93	99	99
	2	100	96	99	99	97	99	100
Check	0	0	0	0	8	0	10	8

Plants treated with 2,4-D had refoliated in September, but those treated with picloram did not. The sprays containing combinations of picloram and 2,4-D were nearly as effective as the picloram sprays.

All of the herbicides killed a high percentage of the mesquite leaves, but the amine salt of 2,4,5-T did not give high kills as consistently as the other herbicides (table 4.21).

Winged elm leaves are not as easily killed by foliar sprays as mesquite and the values for initial kill range from 41 to 88 percent (table 4.22). Picloram and 2,4,5-T initially killed about the same percentage of leaves, but there was greater refoliation on plants treated with 2,4,5-T.

TABLE 4.22.--Percentage of dead leaves on winged elm plants treated with picloram, 2,4,5-T, and picloram: 2,4,5-T at three rates on two dates

Herbicide	Rate	Treatment Dates			
		May 9, 1965		May 31, 1965	
		2 wk.	4 mo.	3 wk.	3 mo.
	Lb. per acre	Percent			
Picloram	1	48	73	41	75
	2	65	83	46	76
	3	74	85	53	86
2,4,5-T	1	58	51	41	35
	2	63	40	46	68
	3	73	50	78	65
Picloram:2,4,5-T (1:1)	1	50	56	53	55
	2	76	70	59	72
	3	88	96	75	83
Check	0	3	4	1	10

Summary and Conclusions

An irrigated woody plant nursery was established in 1963 for the evaluation of chemicals as defoliants and herbicides. Eight species were established in the nursery. Methods for the propagation and culture of seven of the species were developed. Mesquite, huisache, and live oak were established with good success by direct seeding in late fall or early spring. Macartney rose and greenbriar were established with plants dug from wild stands and transplanted in the nursery in mid- or late-winter. Good stands of loblolly pine were established in the winter on well-drained soils from seedlings obtained from a commercial nursery, but yaupon seedlings obtained from a commercial nursery were not successfully established. Excellent stands of winged elm and whitebrush were established from seedlings grown from seed in the greenhouse and transplanted to the nursery in early spring.

A summary of the most effective chemicals found for the defoliation and control of seven woody species in the nursery is contained in Table 4.23. The combination of chemicals are those which gave best control of the species.

In general, results obtained with plants in the nursery agree with those obtained with plants in wild stands. The primary differences are the lower rates of application necessary to kill the plants in the nursery, the longer periods of time during which plants remain susceptible to chemicals in the irrigated nursery, and the rapidity with which plants refoliate in the irrigated nursery after sublethal applications of a chemical.

The nursery has enabled us to evaluate many chemicals and combainations of chemicals as defoliants and herbicides during a 3-yr. period. The experiments conducted in the nursery do not substitute for experiments on wild stands of woody plants when information for operational recommendations is needed, but they do bridge the gap between primary screening of chemicals and large-scale field evaluations.

TABLE 4.23.--Best herbicides and herbicidal combinations for defoliation and control of seven woody species growing in an irrigated nursery

Species	Rapid defoliation	Long term control	
		Herbicide	Herbicidal combination
Greenbriar	DSMA	2,4,5-T	Picloram:amitrole
Huisache	Picloram	Picloram	Picloram:paraquat
Live oak	DSMA	Picloram	Paraquat:bromacil
Loblolly pine	Paraquat	Paraquat	- - - -
Macartney rose	DSMA	Picloram	Picloram:2,4-D
Mesquite	DSMA	2,4,5-T	2,4,5-T:picloram
Whitebrush	MCPA	Picloram	- - - -
Winged elm	DSMA	Picloram	Picloram:2,4,5-T

CHAPTER 5

EVALUATION OF HERBICIDES APPLIED TO SOILS

There are basically two objectives for applying herbicides to the soil. The first is to kill the woody plants on an area but permit revegetation by grasses and herbs. Relatively low herbicidal rates or selective herbicides are used for that purpose. The second objective is long-term sterilization of the soil to keep it devoid of vegetation for long periods of time. High rates of nonselective herbicides are required for soil sterilization. Both types of applications were made in Texas and Puerto Rico on a wide variety of species and vegetation types. The objectives of the work were to determine the effectiveness of the herbicides for killing woody plants and to determine the persistence of control.

Soil Sterilization Studies in Texas

Treatments, at soil sterilant rates, were made in Texas near Victoria, Refugio, Llano, Carlos, and Livingston on duplicate square rod plots. This provided an appreciable range of climate and edaphic conditions, as well as vegetational differences.

The dominant vegetation in the research site at Victoria, Tex., was a thick stand of live oak. Herbaceous vegetation included little bluestem, brownseed paspalum, yellow indiangrass, threeawns, lovegrasses, grisebach bristlegrass, bitter sneezeweed, and lindheimer croton. Soil at the Victoria site was a Katy, gravelly sandy loam. The average profile consists of a light brownish gray, gravelly, sandy loam surface layer about 20 in. thick with a pH of 5.5 and a gravel content of 10 to 30 percent. Subsoil is gray sandy clay with yellowish brown and red mottles centered around small iron concretions. The amount of sand increases with depth and a few calcium carbonate concretions occur at 54 to 60 in. in many places. Annual precipitation is 36 in.

Huisache and mesquite were the dominant woody species at the research site near Refugio, Tex. Associated herbaceous vegetation included rhodesgrass, curly mesquite, bristlegrasses, little bluestem, lovegrasses, sandbur, various species of greenthread and paspalum, broomweeds, toadflax, sedges, bitter sneezeweed, and lindheimer croton. Soil at the Refugio research site was a Miquel fine sandy loam, shallow phase. The average thickness of the surface soil was about 6 in. The subsoil was dense and only slowly permeable by percolating water. Annual precipitation is 34 in.

The dominant woody species at the research site near Llano, Tex., was whitebrush. Other woody species included mesquite, Texas persimmon, prickly pear, and tasajillo. The major perennial grasses in the area included sideoats grama, curly mesquite, vine mesquite, and buffalograss. A variety of herbs and annual grasses were also present. The granite soils at the Llano site contain from 30- to 50-percent gravel. The surface soil is deep, with 18 to 24 in. of a light brown, gravelly, loamy sand. The subsoil is a red, or yellow and gray, clay. The surface soil absorbs water well but the heavy subsoil takes it slowly. Annual rainfall averages 29 in. per year.

The association of woody species at the research site near Carlos, Tex., is dominated by post oak, blackjack oak, and yaupon. Associated herbaceous species include little bluestem, bristlegrass, bitter sneezeweed, and various species of paspalum. Soil at the Carlos site is an Axtell fine sandy loam, shallow variant. The A horizon is a gray, fine sandy loam to a depth of 5 to 10 in. The dark, heavy clay of the B horizon causes a perched water table in rainy seasons, but the C horizon permits excessive sub-drainage. Consequently, the soil has characteristics of both a wet and a dry soil. Mean annual rainfall is 39 in.

There were a greater number of woody species at the research site near Livingston, Tex., than at the other research sites in Texas. Principal woody species included sumac, sassafras, American beech, Allegheny chinquapin, saw greenbriar, and sweetbay magnolia. Many species of herbs and grasses, together with the woody plants, provide an extremely complex association. Dominant forage grasses include species of bluestem, dropseed, panicum, paspalum, muhly, lovegrass, uniola, and indiangrass. Yankeeweed, greenbriar, and yaupon are common invaders. Soil at the Livingston site is Segno fine sand. The soil is deep and well drained. Plant nutrients are leached downward readily and the same could be expected for herbicides. Average annual rainfall is 48 in.

Spring and fall applications were made on duplicate, square rod plots at all research sites. Fenuron, fenuron-TCA, monuron-TCA, BMM, and picloram were applied as granular or pelleted formulations. Sodium chlorate and sodium arsenite were mixed with sand and broadcast over the plot area. Bromacil, prometone, and erbon were applied in water with a hand-carried, boom sprayer. Rates of application and the results that were obtained are given in table 5.1.

TABLE 5.1.--The number of months after treatment that 90 to 100 percent defoliation of woody species was maintained at five research sites in Texas[1]

Herbicide	Rate	Number of months after treatment at--									
		Victoria		Refugio		Llano		Carlos		Livingston	
		Summer application	Fall application	Summer application	Fall application	Summer application	Fall application	Summer application	Fall application	Summer application	Fall application
	Lb. per acre	No. of months									
Fenuron	40	24	20	24	20	3	0	27	21	5	--
	160	24	20	24	20	24	20	27	21	5	--
Bromacil	40	24	20	24	20	24	20	27	--	5	--
	160	24	20	24	20	24	20	27	21	26	21
Fenuron-TCA	40	24	20	24	20	0	0	27	21	5	--
	160	24	20	24	20	12	8	27	--	5	--
Monuron-TCA	35	24	20	24	20	0	0	0	21	0	--
	141	24	20	24	20	24	20	0	21	5	--
BMM	392	24	20	24	20	24	20	27	21	0	--
	980	24	20	24	20	24	20	27	21	5	--
Sodium chlorate	396	0	0	24	0	24	20	0	--	0	--
	990	0	20	0	0	24	20	0	--	0	--
Sodium arsenite	371	24	20	0	20	12	8	6	--	0	--
	940	24	20	0	20	12	1	27	21	0	--
Picloram	10	24	12	24	0	24	20	27	21	5	--
	80	24	20	24	20	24	20	27	21	5	--
Prometone	40	16	20	24	20	24	20	27	21	26	21
	160	24	20	24	20	24	20	27	--	26	21
Erbon	80	24	20	24	0	24	8	0	--	5	--
	160	24	20	24	0	12	8	6	21	5	--

[1] Twenty or more months represent the last observation; control may extend for a longer period. Less than 20 mo. indicates vegetative recovery by the time the last observation was made.

Bromacil, erbon, prometone, and sodium arsenite were the only herbicides that gave an appreciable effect within 1 or 2 wk. after treatment. A longer period of time was required for all other herbicides.

The degree of control obtained from spring and fall treatments was about the same. Although only fragmentary data are available for fall treatments at the Livingston site, season of treatment did not appear to be any more important than at the other sites. Bromacil and prometone provided excellent control at the Livingston site regardless of time of treatment.

The rates applied in this study were high and consequently there was little superiority of one herbicide over another. The most striking difference to be noted is that persistence of control was much shorter at Livingston than at any of the other research sites. This was no doubt due to higher rainfall and a more permeable soil. Only bromacil and prometone provided 90 percent or greater control at Livingston for the duration of the study.

Fenuron controlled brush effectively at Victoria, Refugio, and Carlos with 40 lb. per acre, and at all sites except Livingston with 160 lb. per acre. Control of herbaceous vegetation at either of the two rates lasted about 1 yr.

Bromacil was one of the most effective and persistent soil sterilants tested. The 160-pound-per-acre rate controlled most of the brush and herbaceous species at all locations for the duration of the experiment. Cacti were not affected. The 40-lb.-per-acre rate was equally effective at all Locations except Livingston. Excellent grass and brush control at Llano and Refugio is shown in figure 5.1. Curly mesquite and vine mesquite were the first grass species to reenter treated plots. Some lateral movement of bromacil onto adjacent untreated areas was noted, particularly at Victoria, Carlos, and Llano.

Fenuron-TCA was less effective at Llano than at other research sites. This herbicidal combination had no advantage over fenuron alone.

Monuron-TCA gave results similar to Fenuron-TCA.

BMM controlled brush for the duration of the experiment at all research sites except Livingston. Herbaceous vegetation was usually controlled for 1 yr. or less.

Sodium chlorate was generally less effective than other herbicides. However, it gave excellent control of whitebrush at Llano. The control of herbaceous vegetation varied, but results were poor in many cases.

Sodium arsenite was especially effective for controlling live oak and associated vegetation at Victoria, but it did not control the brush at Llano or Livingston. The initial control of herbaceous vegetation was often as good as with bromacil, but control was not as persistent.

Figure 5.1.—Excellent grass and brush control obtained with 40 lb. per acre of bromacil at (A) Llano and (B) Refugio. Photos were taken 12 and 27 mo. after treatment, respectively.

The higher rate of picloram gave excellent brush control, but the control of herbaceous vegetation was not outstanding at any location. The lower rate of picloram did not control mesquite at the Refugio site nor did it control many of the native grasses. An excellent stand of little bluestem at the Victoria site, following a spring application, indicates that this species is quite tolerant to picloram. It is also possible that picloram had been leached beyond the root zone. It is highly soluble in water and highly mobile in the soil.

Prometone, like bromacil, controlled brush at all five research sites. It was less effective than bromacil for controlling herbaceous vegetation, however. Common yellow woodsorrel was one of the first species to invade the plot that had been treated with prometone.

Erbon provided its best brush control at Victoria. Fall treatments at Refugio and Llano were poor, as were spring treatments at Carlos. Erbon seldom controlled the herbaceous vegetation for long periods.

Brush Control Studies in Texas

Additional studies were made to determine if lower rates of the herbicide would control the brush species in Texas. Some of the herbicides discussed previously were used, but at lower rates. No particular thought was given to long term sterilization of the soil. Fenuron and picloram were compared for the control of live oak at the Victoria site, and huisache and mesquite at the Refugio site. In addition, fenuron and picloram were compared with bromacil for the control of live oak at the Victoria site. Rates of the herbicides that were used, and the results that were obtained 4 mo. and 1 yr. after treatment, are shown in table 5.2.

Fenuron at 10 lb. per acre gave good control of live oak and huisache, but was relatively ineffective for the control of mesquite. Picloram also gave good control of live oak and huisache but again the effect on mesquite was negligible. Picloram at 5 lb. per acre was as effective or more effective than fenuron at 10 lb. per acre.

Bromacil was tested only on live oak. Earlier tests had shown it to be effective for controlling

TABLE 5.2.--Percentage defoliation of live oak, huisache, and mesquite 4 mo. and 1 yr. after treatments with fenuron, picloram, and bromacil to the soil

Herbicide	Rate	Defoliation of --					
		Live oak		Huisache		Mesquite	
		4 mo. after treatment	1 yr. after treatment	4 mo. after treatment	1 yr. after treatment	4 mo. after treatment	1 yr. after treatment
	Lb. per acre	Percent					
Fenuron	1	--	--	20	0	50	5
	2	78	80	50	30	20	5
	5	90	85	88	63	20	10
	10	92	95	93	98	20	48
Picloram	1	--	--	75	43	30	5
	2	88	68	68	55	95	--
	3	92	68	75	60	20	10
	4	92	60	100	100	50	10
	5	94	90	100	100	50	15
	10	98	98	100	100	--	--
Bromacil	2	90	98	([1])	([1])	([1])	([1])
	4	93	100	([1])	([1])	([1])	([1])
	8	97	100	([1])	([1])	([1])	([1])
	12	98	100	([1])	([1])	([1])	([1])
	16	99	100	([1])	([1])	([1])	([1])
	20	100	100	([1])	([1])	([1])	([1])
	40	100	100	([1])	([1])	([1])	([1])

[1] Not treated.

live oak but much less effective on other species. The data indicate that bromacil was more effective for the control of live oak than was picloram. For example, 2 lb. of bromacil resulted in 98 percent defoliation 1 year after treatment, while 10 lb. of picloram were necessary to provide 98-percent defoliation.

Woody species are differentially susceptible to herbicides. If herbicides applied to the soil are to be used for the control of woody plants in an area having a high diversity of woody species, then high rates of the herbicide must be used to reduce the degree of differential susceptibility.

Brush Control Studies in Puerto Rico

Herbicidal applications were made to the soil in Puerto Rico to test their effectiveness for controlling woody species. The tests were conducted in a dry, deciduous thorn forest (Guanica), a semideciduous montane forest (Maricao), and an evergreen rain forest (El Verde). Three replications of 60- by 80-ft. plots were treated at Guanica and El Verde. Only two replications were treated at Maricao because of topographic limitations. The herbicides were applied as granular or pelleted formulations, or as liquid adsorbed on vermiculite. In all cases enough vermiculite was added so that the same amount of bulk material was applied to each plot.

The Guanica site was located in the Guanica Commonwealth Forest at a latitude of 17°58'56" N and a longitude of 66°51'21" W. The site was a flat, alluvial fill at an elevation of 195 ft., surrounded by hills from 330 to 650 ft.

Soil at the Guanica site is Jacana clay, 20 to 36 in. deep, with a permeability of 0.63 to 2.0 in. per hour. The surface soil consists of an 8-in. layer of friable, irregular-shaped granular, alkaline, slightly plastic, brown clay or silty clay. This layer gradually changes to dense medium plastic, alkaline, yellowish brown or light brown clay, 8 to 10 in. thick, which grades through disintegrated, rotten volcanic rock and rests on hard bedrock at a depth ranging from 15 to 40 in. depending on the slope. Bedrock was usually deeper at the sampling site because of alluvial deposition. Annual rainfall, extrapolated from surrounding gages, is about 30 in., most of it falling from May through October. Prolonged droughts are common.

Vegetation in the general area of the Guanica site is a xerophytic forest of shrubby trees 10 ft. or more high. Characteristic species included ucar, zarcilla, burro prieto, almácigo, tea, and corcho bobo. Various cacti emphasized the xerophytic nature of the area. The most impressive cactus was sebucán, which often reached a height of 25 ft. or more. The research site also contained a large number of campeche, which had been planted in 1924. At the time of treatment campeche and zarcilla comprised about 90 percent of the woody plants. Some caoba dominicana was also present. Thirty-five woody species were reported for the Guanica site.

The Maricao reseach site is located in the Maricao Commonwealth Forest at a latitude of 18°09'23" N and a longitude of 66°59'45" W. Elevation is 2,300 ft. About one-half of the research site is relatively flat; the remaining half drops sharply to the west-southwest with slopes up to 45°.

Soil at the Maricao site is a Nipe silty clay derived from serpentine. It is a lateritic soil with silicon dioxide decreasing and aluminum and iron oxide increasing with depth. Clay particles are grouped in clusters and do not have the plastic nature of other clays. Consequently, Nipe clay is excessively permeable and well-drained, making it well-aerated, but more droughty than would ordinarily be expected. Annual rainfall is about 80 in. Most of the rainfall occurs from July through October.

Maria was the dominant woody species at the Maricao site. It comprised 18.6 percent of all woody stems greater than 3/4 inch d.b.h. A total of 106 species were recorded on the site.

The El Verde site is located in the Luquillo National Forest at a latitude of 18°17'40" N, and a longitude of 65°51'08" W. Elevation is 1,800 ft. The area is on the northwest slope of the Luquillo Mountains and thus falls within the rain shadow caused by the main mountain mass that intercepts the moisture-laden tradewinds. Annual rainfall is about 120 in., most of it falling from July through October. Extended droughts in this area are unknown.

Soil at the El Verde site is Los Guineos clay loam, characterized by a surface layer of medium plastic clay often underlain by a layer of mottled gray and rusty-brown plastic clay with poor internal drainage. Moisture retention in this soil is much higher than that in the Nipe clay found at Maricao. Roble was the dominant woody species, comprising 20.9 percent of the woody stems in the research site. A total of 88 species were recorded for the area. A list of the common woody species is given in table 5.3.

Picloram, dicamba, bromacil, prometone, diuron, and fenac were tested at rates of 3, 9, and 27 lb. per acre. The herbicides are representatives of six chemical families that have herbicidal properties.

The percentages of defoliation at the three sites is shown in table 5.4. In general, the herbicides were most effective at Guanica (the driest site) and least effective at El Verde (the wettest site). Dicamba was the only exception in that it provided most control at El Verde and least control at Guanica. The most effective herbicide at all three sites was picloram. Dicamba was only moderately effective even at the highest rate. Bromacil and prometone gave very good control at Guanica, but poor control at Maricao and El Verde. Diuron and fenac were ineffective at all research sites.

This test indicated, in a relative way, the amounts of herbicides that must be applied to the soil in order to provide good woody plant control. The data show clearly that the amounts of herbicides must be increased for wetter areas. Only one herbicide, dicamba, provided a greater degree of control at wetter sites than at the dry site. When all herbicides are considered, the data suggest strongly that the amount of herbicide must be increased as rainfall increases. If that is not done, equivalent results will not be obtained.

Another important consideration in wet tropical forests is that the root system of the trees does not extend deep into the soil. On the contrary, in a rain forest particularly, there is usually a mass of roots in the surface

TABLE 5.3.--The most common woody species at the Guanica, Maricao, and El Verde sites and their percentage composition

Scientific name	Common name	Number and percentage composition	
Guanica		No.	Percent
Leucaena leucocephala	Zarcilla	2,513	46.2
Haematoxylon campechianum	Campeche	2,446	45.0
33 other species		479	8.8
Total		5,438	100.0
Maricao			
Callophyllum calaba	Maria	399	18.6
Casearia or Drypetea[1]		186	8.7
Rapanea ferruginea	Mantequero	174	8.1
Alsophila aquilina	Helecho	150	7.0
Terebraria resinosa	Aquilón	96	4.5
Ocotea leucoxylon	Laurel geo	95	4.4
Miconia sintenisii	Camasey	87	4.1
Coccoloba sp.		67	3.1
Linociera domingensis	Hueso blanco	67	3.1
Homalium sp.		64	3.0
Coccoloba pubescens	Moralón	57	2.7
Myrcia deflexa	Cieneguillo	45	2.1
Myrcia splendens	Hoja menuda	41	1.9
Comocladia glabra	Carrasco	35	1.6
Cyathea arborea	Helecho gigante	30	1.4
91 other species		519	24.2
Total		2,142	99.9
El Verde			
Tabebuia heterophylla	Roble	683	20.9
Cyathea arborea	Helecho gigante	352	10.8
Cordia borinquensis	Muñeco	334	10.2
Prestoea montana	Palma de sierra	238	7.3
Miconia prasina	Camasey	201	6.2
Casearia or Drypetea[1]		152	4.7
Psychotria berteriana	Cachimbo	136	4.2
Inga fagifolia	Guamá	132	4.0
Myrcia deflexa	Cieneguillo	93	2.8
Didymopanax mortotoni	Yagrumo macho	84	2.6
Octoea leucoxylon	Laurel geo	79	2.4
77 other species		781	23.9
Total		3,265	100.0

[1] Sterile specimens of these two genera were indistinguishable.

soil and very few roots, if any, in the deeper portions of the soil profile. Such being the case, there is only a short time when roots can pick up the herbicide. After the herbicide is leached beyond the root zone, it is no longer available. Plants not killed by the initial amount of herbicide absorbed will recover. Such a situation is a decided contrast to what is often found for plants whose roots penetrate to a greater depth. Plants with a deep, root system may be defoliated quickly after application of a herbicide to the soil. Those plants often refoliate during a rainy season only to be defoliated again as the deeper roots pick up more of the herbicide.

TABLE 5.4.--Percentage of defoliation and plant kill of all arborescent species in Guanica, Maricao, and El Verde sites approximately 2 years after application of soil-applied treatments

Herbicide	Rate	Guanica		Maricao		El Verde	
		Defoli-ation	Plant kill	Defoli-ation	Plant kill	Defoli-ation	Plant kill
	Lb./acre	Percent					
Picloram	3	70	57	32	21	24	23
	9	92	91	73	57	55	52
	27	99	99	93	89	79	69
Dicamba	3	9	3	12	6	9	6
	9	13	[illegible]	10	10	19	14
	27	22	9	50	41	52	52
Bromacil	3	28	16	11	5	18	15
	9	92	78	29	21	24	22
	27	100	100	38	29	55	54
Prometone	3	9	8	11	3	0	0
	9	62	56	13	5	10	9
	27	99	97	29	21	18	12
Diuron	3	5	2	11	0	0	0
	9	15	11	5	1	3	2
	27	16	10	9	3	8	9
Fenac	3	5	2	15	5	8	0
	9	28	20	11	2	4	2
	27	29	14	19	4	22	9
Check	0	12	6	5	2	1	1

There is little doubt that phytotoxic levels of herbicides are soon leached below the root zone in an area having high rainfall. A series of pictures in figure 5.2 shows this graphically. The plot shown in figure 5.2 had been treated with 27 lb. per acre of picloram. Virtually all of the trees, and also the herbaceous vegetation on the forest floor, had been killed by the treatment. One year after the treatment, however, the forest floor was completely covered with species of grass, sedge, and Ipomaea. Had phytotoxic amounts of the herbicide been present in the upper layer of soil, such a dense cover of herbaceous vegetation 1 yr. after treatment would not have been possible.

The studies that have been reported for Texas and Puerto Rico show that woody plants can be killed with herbicides applied to the soil. Soil sterilization can be obtained for relatively long periods of time if enough herbicide is used and there is not too much rainfall. Some woody species will be killed by one herbicide but not with another. Complete woody plant control in areas having a high species diversity can only be achieved if enough herbicide is applied to overcome the effects of differential species susceptibility. The necessary rate varies with herbicides, but could be as low as 10 lb. per acre in dry areas, and as much as 27 lb. per acre, or more, in extremely wet areas.

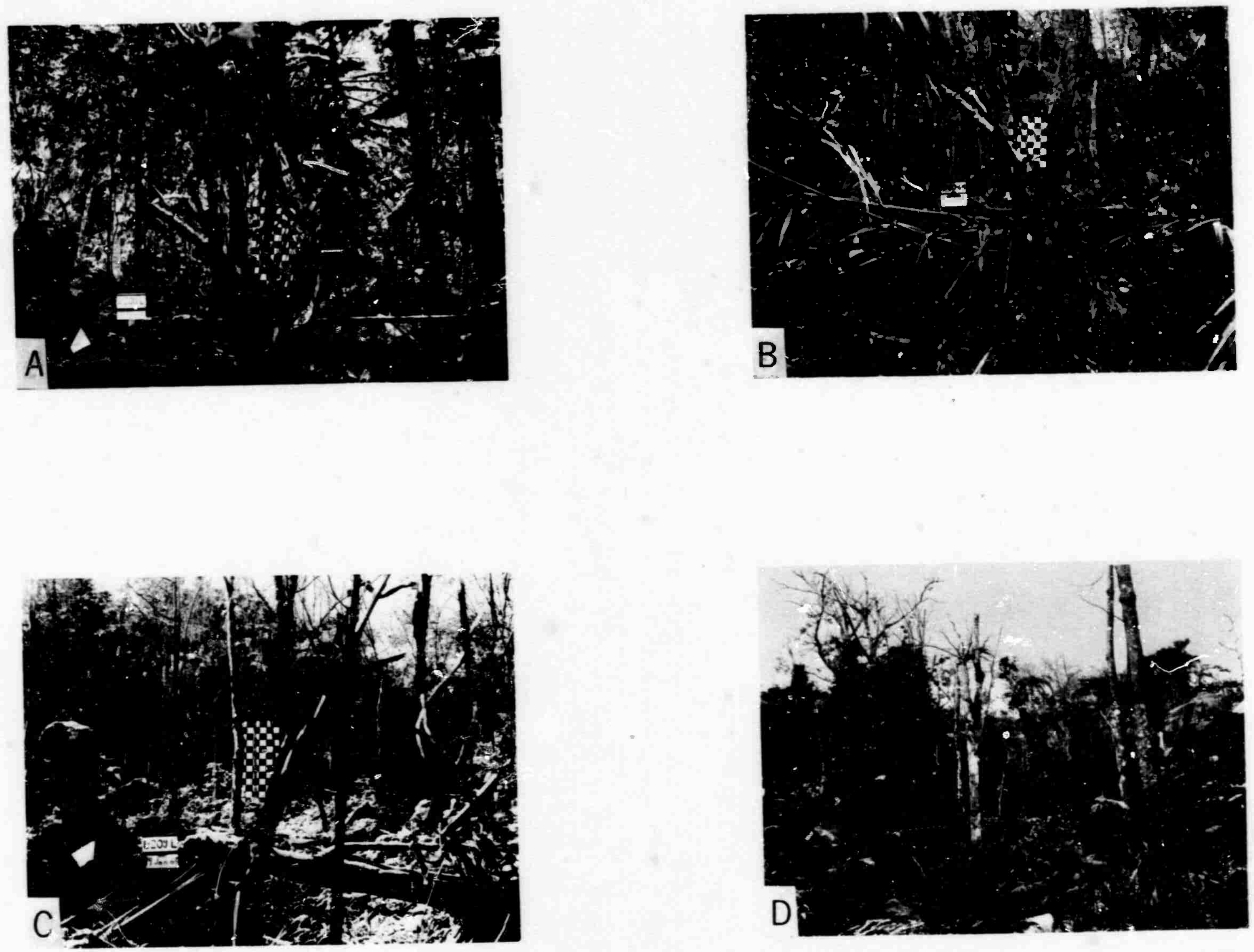

Figure 5.2.--The death and subsequent regeneration of vegetation on a plot at El Verde that had been treated with 27 lb. per acre of picloram applied to the soil. Photos were taken A, before treatment; B, 4 mo.; C, 12 mo., and D, 24 mo. after treatment.

CHAPTER 6

HERBICIDE RESIDUES IN SOIL

The persistence of herbicides in soil may be desirable or undesirable depending on the purpose for which they are applied. In general, a low level of persistence is desirable when herbicides are applied to soil in cultivated crops. The crop grown at the time of herbicidal treatment may be resistant to the herbicide, but the succeeding crop, in a rotational scheme, may be susceptible. Thus, it is important that the herbicide be inactivated in some way before the succeeding crop is planted. In other situations, persistence for long periods of time may be desirable. Industrial sites and roadways are examples of situations where total vegetation control for long periods is desirable.

Our work on herbicide residues in soil involved the development of techniques for determining residue levels and an analysis of the persistence and movement of various herbicides in soils in Puerto Rico and Texas.

Residue Detection

Biological and chemical methods for detecting herbicide residues in soil were already available for a large number of herbicides. The same was not always true for newer herbicides, so methods had to be developed. We were particularly interested in determining the residue levels of picloram in soil because picloram is effective for the control of many woody species. A bioassay for picloram had been developed (5) but there were no chemical methods of detection.

Chemical Method

The presence of three chlorine atoms and two nitrogen atoms in the picloram molecule indicated that it could be detected readily by a gas chromatograph equipped with an electron capture detector. The reliability of gas chromatography for detecting picloram residues in soil was determined by adding known amounts of picloram to the soil, extracting, and analyzing with a gas chromatograph (6). Soil samples to which known amounts of picloram had been added were stirred for 2 min. in 25 ml. of acetone acidified with 0.2 ml. of concentrated HCl per 100 ml. of acetone. The addition of the acid was essential because it insures that any basic salts of picloram will be converted to the free acid and consequently be acetone-soluble. An excess of acid could conceiveably convert the amino group to a quaternary salt thus making the picloram molecule again insoluable in acetone.

The suspension of soil and acetone was suction-filtered through Whatman No. 1 filter paper and the volume of acetone determined. After evaporating the acetone to dryness on a steambath, 4 ml. of boron trifluoride-methanol reagent were added, and the samples again heated until only a trace of methanol remained. The reagent was prepared following a previously published procedure and contained 125 gr. of boron trifluoride per liter of methanol (1). After heating, the beaker was washed with 10 ml. of water and 10 ml. of re-distilled hexane. Both washings were thoroughly mixed in a 50 ml. separatory funnel and the aqueous portion discarded. The content of methylated picloram in 1 microliter of the hexane portion was determined by gas chromatography.

The gas chromatograph used for the study was a Barber-Colman Model 5360 pesticide analyzer. A 6-ft. spiral column was packed under vacuum with 80 to 100 mesh Chromasorb-W coated with 1.5 percent SE 30 oil. The column was heated 24 hours at a temperature of 250° C. before coupling to the detector. An electron capture detector containing radium 226 as the ionization source was employed. The pre-purified nitrogen, used as the carrier gas, was further purified by passing it through a molecular sieve filter. Samples were analyzed at injector, column, and detector temperatures of 295°, 210°, and 240° C., respectively. Carrier gas flow rate was approximately 75 ml. per min.

Standard and recovery curves are shown in figure 6.1. There was a linear relation between picloram content and peak height when the peak was between 20 and 80 percent of full-scale

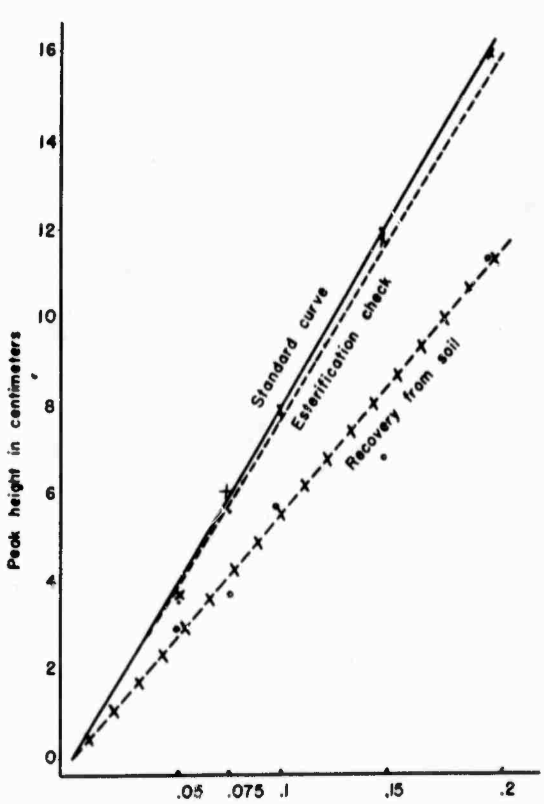

Figure 6.1.--Standard and recovery curves for determining picloram residues in soil.

TABLE 6.1.--The reliability of a chromatographic method of detecting picloram residues in soil

Concentration Added	Concentration Found [1]	Ratio Added/found
P.p.m.	P.p.m.	
0.075	0.06	0.80
0.10	0.095	0.95
0.30	0.34	1.14
1.00	0.80	0.80
1.50	1.68	1.12

[1] Expected recovery = 96.2 ± 19 percent with 95 percent confidence.

deflection. A comparison of curves produced from equal concentrations of the methyl ester of picloram and picloram esterified with boron trifluoride-methanol reagent indicates that the esterification is essentially complete. The recovery curve, however, indicates that the acetone extraction procedure was approximately 75 percent effective in removing picloram from the soil. This correction factor was used in making final calculations of picloram content in field plots.

A check of the reliability of the method over a range of picloram concentrations is shown in table 6.1. The expected deviation between picloram added and picloram found was approximately 20 percent. The lower limit of picloram detection was approximately 0.05 p.p.m. when the sample size was 20 gr. It does not appear that increasing the sample size would increase sensitivity since the detection limits are set by interfering compounds in the procedure rather than the amount of picloram.

Bioassay

A susceptible plant can be used to determine herbicide residues in soil. The sensitivity of a test plant to a herbicide is measured by growth reactions that may vary from abnormal growth characteristics to plant death. Because equipment for chemical analysis was not available, the study of herbicide residues in Puerto Rican soils required development of a standard bioassay test. It was desirable to use a single-test species sensitive to all of the herbicides whose residue levels were studied. It was also desirable to have a test plant that was readily available, easily grown, and had growth characteristics suitable for bioassay studies.

For the bioassay of herbicide residues in the soil, a standard reference curve was prepared for each herbicide to permit a quantitative evaluation of the residues. Cucumbers were used as the bioassay test plant.

Cucumber plants were grown in beach sand for establishing the standard injury curve. The sand was thoroughly washed, steam-sterilized, and dried. Concentrations of 0.001, 0.003, 0.009, 0.027, 0.081, 0.243, 0.729, and 2.187 p.p.m. of bromacil, dicamba, diuron, fenac, picloram, and promotone were added to the sand. A 5,000-gr. aliquot of the sand was weighed and placed on a plastic sheet. The correct amount of herbicide in a uniform aliquot of distilled water was added to the sand and thoroughly mixed. After mixing, the sand was equally divided into four, new, 1-qt. styrene cups that had been thoroughly washed. The concentration series of each herbicide was set up separately, starting with the lowest concentration and finishing with the highest concentration. After the herbicides were mixed into the sand, the cups were placed in the greenhouse and planted with about 8 cucumber seeds (variety Puerto Rico 39). Extreme care was taken to avoid contamination. Untreated series were set up previous to any mixing of herbicides and isolated from the mixing area.

Each sample was thinned to two plants per container approximately 7 days after planting. The cucumber plants were allowed to grow for 28 days. Abnormal growth characteristics were recorded on a 10-point scale where zero equals no effect and 10 equals dead plants. The plant stems and leaves were harvested at the end of the 28-day period and the fresh weight recorded. Plant samples were then dried at 50° C. for 48 hr. and the dry weight recorded. A standard injury curve for each herbicide was developed and the correlations between injury ratings and plant weights determined.

Cucumbers germinated and emerged in all concentrations of all herbicides. Abnormal growth characteristics were not the same for all herbicides. Dicamba, picloram, and fenac caused the same general malformations to cucumber leaves. Pinched leaf margins, leaf rolling, and dark green venation were the most common reactions, and they increased in amount and severity as the herbicide concentration increased. Fenac generally caused a shortening of the plant stem and leaf petioles, but dicamba and picloram caused an elongation. Bromacil caused some leaf rolling and stem elongation to cucumbers, but the most evident reaction was plant chlorosis and eventual death.

Diuron and prometone did not cause significant leaf abnormalities. The typical reaction of cucumber to diuron was plant stunting, chlorosis, and eventual death. Prometone usually caused a mottled appearance on the leaves before chlorosis appeared. The severity of stunting and chlorosis, and the rapidity of death increased as the herbicide concentration increased. Bromacil, prometone, and diuron at 2.187 p.p.m. caused cucumber seedlings to die within 6 to 8 days after emergence.

The standard curves for injury rating of cucumbers resulting from bromacil, dicamba, diuron, fenac, picloram, and prometone are shown in figure 6.2. It was assumed that the sand was an inert substrate with no adsorption of herbicide onto clay particles. All herbicides could be detected at concentrations of 0.009 p.p.m. or less, 28 days after planting. All herbicides at 2.187 p.p.m. caused the cucumbers to die. Cucumbers were sensitive to all the herbicides used in this study, but the sensitivity varied among herbicides. Cucumbers were extremely sensitive to bromacil and dicamba, intermediate in sensitivity to diuron, prometone, and picloram, and least sensitive to fenac.

Correlation coefficients for injury rating versus fresh weight and for fresh weight versus dry weight were significant at the 1-percent level of probability for all herbicides. The data for picloram are given in table 6.2. Even though the correlation between injury rating and fresh weight was statistically significant, the fresh weight of cucumber plants could not be used to detect small amounts of herbicide. Visual observations could easily detect herbicide concentrations that caused growth abnormalities to cucumber leaves, but did not influence fresh or dry weight.

The cucumber bioassay was used to determine levels of herbicide residue in soils for subsequent studies that were made on a number of different soil types in Puerto Rico.

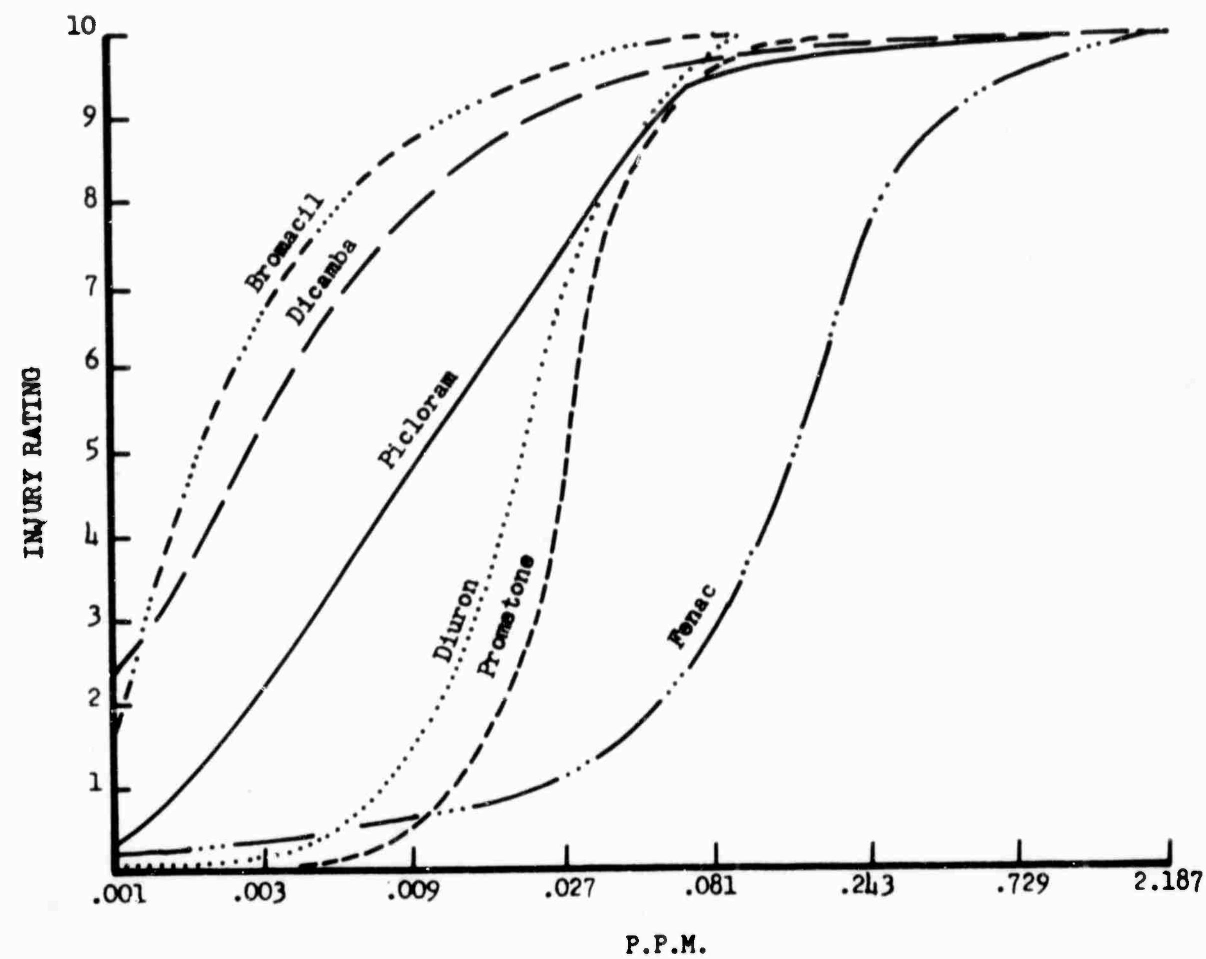

Figure 6.2.--Standard curves for known concentrations of several herbicides using cucumbers as the test plant. Injury ratings are based on a scale of 0 to 10; where 0 = no effect and 10 = dead plants.

TABLE 6.2.--Injury ratings and fresh and dry weights of cucumbers grown for 28 days in sand containing known concentrations of picloram

Picloram concentration	Injury rating[1]	Fresh weight	Dry weight
P.p.m.		--------Grams--------	
0	0	23.7	1.7
.001	0	25.4	1.8
.003	2	20.9	1.7
.009	5	21.0	1.5
.027	7	14.6	0.9
.081	9	3.3	0.5
.243	10	1.4	0.3
.729	10	0	0
2.187	10	0	0

[1] Scale of 0 to 10 where 0 = no injury and 10 = dead plant.

Laboratory Studies

Picloram is an effective herbicide used to control many species of woody plants. It has also shown promise for controlling small infestations of deep-rooted perennial weeds in croplands. Because picloram is highly phytotoxic to many plant species, knowledge of its persistence in soil was needed.

Bioassay studies by Goring, Youngson, and Hamaker (3) indicated that the half-life of picloram in soils varies considerably and that losses range from 58 to 96 percent after 1 yr. Similar studies indicated that picloram was dissipated faster at low rates than at high rates in three Ohio soils (4). After 15 mo., residues were greatest in the heavy-textured soil with the highest organic content.

The information to be presented here concerns the effect of soil type, temperature, moisture, and light on the persistence and movement of picloram in soils (7).

For the persistence studies Houston clay, Axtell sandy loam, and a commercial grade of sand were dried, and 1 kg. of each placed in a cylinder capped with a sieve. Excess water was added and after 6 hr., the water was allowed to drain through the sieve. When drainage ceased, the soils were reweighed and the increased weight was used as the measure of the water required to bring the soils to field capacity. Picloram was applied as the potassium salt at rates of 0.25 and 1.00 p.p.m., or approximately 1/2 and 2 lb. per acre, respectively. After mixing, four replications of each soil were placed in plastic bags and water added to bring the soils to field capacity, or to 0.1 field capacity. Soils at both moisture levels were kept in small growth chambers at 4°, 20°, or 38° C. Soils maintained at 38° were weighed and watered twice weekly, weekly at 20°, and biweekly at 4° C. Samples were taken for residue determination 1, 3, 6, and 12 mo. after application of the herbicide. Each sample consisted of a 20-g. core taken through the depth of the soil.

For the movement studies, six plastic pipes, 8 cm. in diameter and 64 cm. long, were capped with screen wire and filled with each of the above soil types. The soil was moistened to facilitate packing and then allowed to dry for 2 wk. Three replications of each soil type were moistened to field capacity, while the other three remained dry. One mg. of the potassium salt of picloram was applied uniformly to the soil surface with a small mist atomizer. Water, equivalent to 1 in. of rain, was dripped onto the soil over a period of 1 hr. Samples were taken at various depths, 1, 4, and 24 hr. after watering was completed. The 0 to 2.5 and 2.5 to 7.5 cm. depths were taken from vertical cores while samples from greater depths were taken from horizontal cores made through slits in the plastic pipes.

For the photo decomposition studies, 1 mg. of picloram was spread evenly over the surface of an 8 cm. petri dish or on soil placed within the petri dish. Four replications of each treatment were exposed to sunlight, ultraviolet light, and darkness. The source of ultraviolet light was a mineralight, Model R-51 lamp, which provided approximately 155 μw. of shortwave ultraviolet radiation per centimeter. The picloram content was determined after 48 and 168 hr. exposure to the various light conditions.

The method of extraction of picloram residues from the soil and its analysis by gas chromatography were described previously in this chapter.

A detectable residue of picloram was present after 1 yr. at all temperature and moisture levels in all soils, even at the 1/2-lb.-per-acre rate (table 6.3). As a check on the chromatographic procedure, black valentine beans were planted in the soil not required for chromatographic analysis. These tests also indicated the presence of picloram in all soils.

Although present in all soils, picloram concentrations were reduced to approximately 25 and 15 percent, respectively, of the amount originally applied at the 1/2- and 2-lb.-per-acre rates. Picloram was more persistent after 1 yr. at 4° C. than at higher temperatures. Picloram was also more persistent in clay or sandy loam than in sand.

More frequent waterings were required to maintain the desired moisture levels at the higher temperatures. Picloram leaches more readily from sand than from other soils, so it was possible that picloram was not being degraded faster, but was being leached to the bottom of the plastic bag. To investigate

TABLE 6.3.--The effects of temperature, moisture, and soil type on the persistence of picloram applied at rates of 0.25 and 1.0 μg. per g. of soil

Soil type	Temperature	Moisture[1]	Time after treatment at two rates							
			1 mo.		3 mo.		6 mo.		1 yr.	
			0.25	1.00	0.25	1.00	0.25	1.00	0.25	1.00
	°C.		μg. per g.							
Houston Clay	4	1.0	0.14	0.54	0.12	0.42	0.08	0.26	0.08	0.20
		0.1	.18	.82	.12	.27	.08	.28	.10	.22
	20	1.0	.18	.42	.14	.46	.09	.20	.03	--
		0.1	.22	.82	.14	.45	.08	.26	.05	.20
	38	1.0	.16	.33	.03	.44	.03	.12	.03	--
		0.1	.14	.90	.08	.44	.05	.26	.06	.34
Axtell Sandy Loam	4	1.0	.10	.42	.10	.28	.09	.32	.12	.24
		0.1	.12	.52	--	.46	.14	.44	.11	.24
	20	1.0	.12	.45	.10	.38	.08	.25	.04	.10
		0.1	.16	.52	.16	.43	.12	.40	.08	.14
	38	1.0	.10	.52	.10	.40	.08	.32	.05	.14
		0.1	.10	.54	.14	.41	.08	.42	.06	.12
Sand	4	1.0	.12	.44	.07	.14	.06	.15	.08	.11
		0.1	.21	.54	.10	.36	--	.24	.12	.15
	20	1.0	.12	.38	.06	.19	.04	.17	.03	.08
		0.1	.11	.46	.08	--	.04	--	.06	.08
	38	1.0	.10	.38	.03	--	.04	.09	.02	.06
		0.1	.12	.36	.10	.34	--	.20	.04	.07

[1] Field capacity and 0.1 field capacity.

TABLE 6.4.--The effect of soil and moisture content on downward movement of picloram after surface application of 1 in. of water in 1 hr. to soil at field capacity and air dry

Soil type	Time interval	Soil depth (inches) and moisture content before watering[1]									
		0 to 1		1 to 3		3 to 6		6 to 12		12 to 24	
		FC	AD	FC	AD	FC	AD	FC	AD	FC	AD
	Hours	μg. per g.									
Sand	1	0.06	0.18	0.06	0.19	0.04	0.16	0.12	0.14	0.12	0.14
	4	.09	.10	.06	.11	.07	.09	.10	.09	.19	.09
	24	.06	.05	.07	.04	.03	.04	.05	.06	.13	.12
Clay	1	.66	.95	.64	.82	.28	(2)	.06	(2)	(2)	(2)
	4	.47	.97	.58	.63	.38	(2)	.08	(2)	(2)	(2)
	24	.61	.93	.55	.65	.40	(2)	.07	(2)	(2)	(2)
Sandy Loam	1	1.08	1.37	.81	.89	.46	.11	(2)	(2)	(2)	(2)
	4	--	.93	--	.87	--	.31	--	.05	--	.04
	24	.81	.92	.52	.68	.29	.14	.14	.06	.03	--

[1] FC = Field capacity, AD = Air dry.
[2] None detectable.

this possibility, each plastic bag was rinsed with 0.1 N sodium hydroxide after completion of the experiment. These rinsings contained the herbicide so we concluded that picloram is quite stable in soil and that leaching is an important means of dissipation.

The effect of soil type and moisture content on downward movement of picloram following a simulated rain of 1 in. in 1 hr. is shown in table 6.4. After 1 hr., simulated rain had moved the picloram at least 12 to 24 in. in sand at both field capacity and 0.1 field capacity. After 24 hr., the herbicide was more concentrated at the lower depths. Picloram moved to a depth of only 2-1/2 in. at 0.1 field capacity and 6 to 12 in. at field capacity in Houston clay. Movement in Axtel sandy loam was 6 to 12 in. at 0.1 field capacity and 12 to 24 in. at field capacity. As a check on the reliability of the column technique, four 5- by 5-ft. field plots of clay soil were treated with 1 lb. per acre of picloram. Water, equivalent to 1 in. of rain, was applied in an hour, using a hand sprayer from which the nozzles had been removed but the screens left in place. After 24 hours, the picloram content was 0.95, 0.78, and 0.04 p.p.m. at 0 to 1, 1 to 3, and 3 to 6 in., respectively. No picloram was detected below the 6-in. depth. This is in agreement with the movement demonstrated in the clay columns.

Herbicides are often subjected to long periods of sunlight before being leached into the soil. Sunlight and ultraviolet light applied artificially are known to deactivate some herbicides. Picloram was deactivated more by ultraviolet light than by sunlight. However, the ultraviolet source was continuous over the entire test period. Chromatographic analyses indicated that 60 percent of 1 mg. of picloram applied to petri dishes was degraded by ultraviolet light after 48 hr., whereas 35 percent was degraded by sunlight. After 1 wk.'s exposure, more than 90 percent was degraded by ultraviolet light and 65 percent by sunlight. Degradation from the soil surface was considerably slower. In soil, only 15 percent of the picloram was degraded by a week's sunlight. These studies were conducted in November so degradation by sunlight was probably near its minimum. To insure that picloram was being degraded by light, rather than volatilized, 4 petri dishes containing 1 mg. of picloram were stored in a forced-air oven at 55° C. for a week. Less than 5 percent of the picloram was lost under these conditions. Since the temperature under the ultraviolet lamp was only 26° C., the loss of picloram is apparently due to photo decomposition rather than volatilization.

Field Studies

Puerto Rico

The persistence and movement in soil of bromacil, dicamba, diuron, fenac, picloram, and prometone were studied in three soil types in Puerto Rico. The herbicides were applied at rates of 3, 9, and 27 lb. per acre on three replications in a randomized block design (2). The herbicides were applied with a cyclone seeder as granules, pellets, wettable powders, or liquids adsorbed on vermiculite. Vermiculite was used as a carrier to provide additional bulk for all treatments.

The soil type at the research site in the Guanica Commonwealth Forest is Jacana clay. It is an aluvial soil normally less than 36 in. deep with very low permeability. Annual rainfall at the Guanica site is estimated at approximately 30 in. and occurs largely from July to October. The recorded annual rainfall at the site for 1964 and 1965 was 27.88 and 25.00 in., respectively. The soil type at the research site in the Maricao Commonwealth Forest is Nipe clay, an excessively permeable, well-drained, lateritic soil derived from serpentine. Rainfall is distributed throughout the year, but December to May is the driest period. The recorded annual rainfall at the site for 1964 and 1965 was 84.64 and 109.88 in., respectively. The soil type at the research site in Luquillo National Forest is Los Guineos clay loam, a plastic clay with poor internal drainage. The annual rainfall is estimated to be over 100 in. The highest rainfall normally occurs from July to October, but droughts are unknown. The recorded annual rainfall near the site was 85.78 and 126.12 in. for 1964 and 1965, respectively.

The soils at the three research sites were sampled 3, 6, and 12 mo. after treatment. Duplicate soil samples were collected at random from depths of 0 to 6, 6 to 12, 12 to 24, 24 to 36, and 36 to 48 in. Each of the soil depths was analyzed separately. In some cases, the soil was not 48 in. deep, so samples were collected to the maximum depth possible. The samples were placed directly in the 1-qt. styrene cups, then sealed, and transferred to the greenhouse where a bioassay was conducted. The bioassay was described previously in this chapter.

Three months after application all the herbicides had moved downward in the soil to the 36- to 48-in. depth. The bioassay data indicated that persistence of the herbicides in the soil 1 yr. after treatment was in the order: fenac>prometone>picloram>diuron>bromacil>dicamba.

The persistence of the herbicides was generally greatest in the driest area (Guanica), and least in the wettest area (Luquillo) (fig. 6.3).

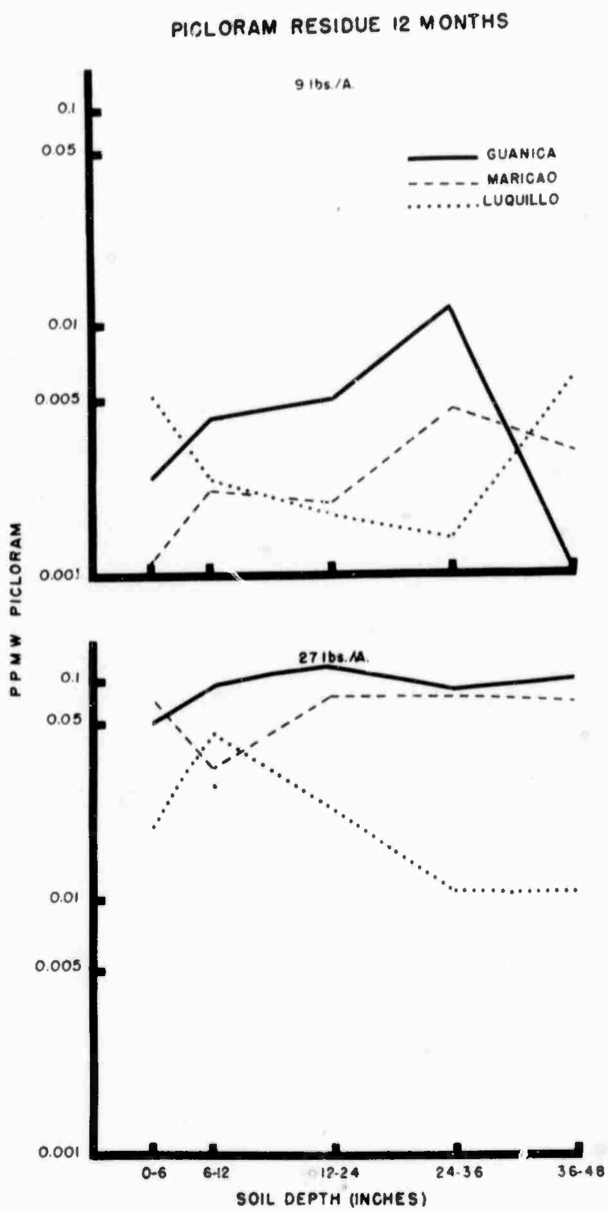

Figure 6.3.--Picloram residue at various depths in three forest areas of Puerto Rico 12 mo. after application.

One year after application, the residue of picloram in plots treated with 27 lb. per acre remained at relatively high concentrations at all test sites. The presence of picloram in plots treated at 9 lb. per acre could be easily detected 1 yr. after treatment, but the concentrations were about 10 times lower.

Texas

Picloram residues were also studied in two soil types in Texas. Field sites were selected in the Gulf Coast Prairie near Victoria and in the Post Oak Savannah near College Station. The soil at the Victoria site is a Katy gravelly sandy loam with a variable quantity of gravel in the lower profile. The average profile consists of a light brownish gray, gravelly sandy loam surface layer about 20 in. thick, having a pH of 5.5 and a gravel content of 10 to 30 percent. The subsoil, or B horizon, is gray sandy clay with yellowish brown and red mottles centered around small iron concretions. It has a moderate to coarse blocky structure and a pH from 5.0 to 6.0. The amount of sand increases with depth and a few calcium carbonate concretions occur at 54 to 60 in. in many places.

The soil at the College Station site is an Axtell fine sandy loam, shallow variant. The A horizon is a gray fine sandy loam to a depth of 5 to 10 in. The dark heavy clay of the B horizon causes a perched water table in rainy seasons, but the stratified C horizon gives excessive sub-drainage. Consequently, the soil has characteristics of both a wet and dry soil.

Picloram was applied at rates of 2 and 8 lb. per acre. The picloram was diluted with water and applied in a volume of 10 gal. per acre with a contourmatic boom sprayer positioned 15 ft. above the brush vegetation.

Soil samples were taken immediately, 1 day, and 2, 6, 12, 26, and 52 wk. after treatment. Samples taken immediately and 1 day after treatment were obtained from the surface 2 in. of soil. Samples were taken from four locations within a plot and mixed to form a composite sample. Two weeks after treatment, samples were taken from the soil surface and at the 5- to 7-in. depth. Later samples were taken at the surface, 5 to 7, 11 to 13, and 23 to 25 in. Care was taken to prevent contamination

TABLE 6.5.--Picloram residues in two Texas soils

Soil type	Rate	Soil depth[1]	Residues at specified times after treatment						
			Immediately	1 day	2 wk.	6 wk.	12 wk.	26 wk.	52 wk.
	Lb. per acre	In.	P.p.m.						
Axtell fine sandy loam	0	1,6,12,24	0	0	0	0	0	0	0
	2	1	1.00	0.89	0.06	0	0	0	0
		6	--	--	0.13	0	0	0	0
		12,24	--	--	--	0	0	0	0
	8	1	2.02	1.54	0.16	0.06	0	0	0
		6	--	--	0.72	0.33	0.08	0.05	0
		12	--	--	--	0.18	0.16	0.06	0
		24	--	--	--	0.16	0.07	0.05	0
Katy gravelly sandy loam	0	1,6,12,24	0	0	0	0	0	0	0
	2	1	0.22	0.39	0.08	0.08	0	0	0
		6	--	--	0.05	0	0	0	0
		12,24	--	--	--	0	0	0	0
	8	1	1.38	1.30	0.25	0.24	0.06	0.05	0
		6	--	--	0.06	0.05	0.12	0.07	0
		12	--	--	--	0.06	0.06	0.11	0
		24	--	--	--	0.05	0.05	0.05	0

[1] Plus or minus 1 in.

and mixing of soil samples. The soil samples were placed in airtight plastic bags, immediately frozen, and stored until analyses were made by gas chromatography.

The residue data are shown in table 6.5. The picloram was applied in an aqueous solution from 15 ft. above the brush, so much of it was intercepted before reaching the soil. Assuming an acre furrow-slice weight of 2 million lb., and a sampling depth of 2 in., data taken immediately after spraying indicate that approximately 25 percent of the picloram reached the soil surface at the College Station site, but only 10 percent reached the soil surface at the Victoria site. Variation of brush density is the most plausible explanation for the higher picloram content at College Station. The Victoria site was virtually covered with live oak while the mixed brush at College Station was quite scattered.

The initial concentration of picloram was greater at the College Station site, but its persistence in the surface soil was greater at the Victoria site. At College Station, no detectable residue was present in the surface soil after 12 wk. even at the 8-lb.-per-acre rate, and within 2 wk., most of the picloram had moved to a depth of 6 in. At Victoria, the concentration of picloram at 6 in. did not exceed that at the surface until the twelfth week, and a detectable amount remained at the surface after 26 wk. at the 8-lb.-per-acre rate. Rainfall was apparently the principle factor regulating the movement of picloram. There were 8.8 in. of rain within 26 wk. after treatment at the Victoria site and 15.9 in. of rain during the same period at the College Station site.

No detactable residue was present after 1 yr. at either location at any rate or depth. To insure that any within-plot variation would be detected, 25 samples from an 8-lb.-per-acre plot at College Station were analyzed individually. None of the samples had a detectable residue of picloram. As a further check, black valentine beans were planted in the soil not required for chromatographic analysis. The beans developed normally in all plots.

Puerto Rico and Texas

A final study on picloram residues in soils of Puerto Rico and Texas was conducted at equivalent rates of picloram application. Rates of 1, 3, and 9 lb. per acre were applied to three soils in Puerto Rico and two soils in Texas.

The soils in Puerto Rico were Nipe clay, Fraternidad clay, and Catano sand. Nipe clay is a well-drained, highly permeable soil with low natural fertility and is found in areas that have more than 70 in. of annual rainfall. Fraternidad clay is a calcareous, poorly drained soil with medium fertility that is usually found in areas having less than 40 inches of annual rainfall. Catano sand is an alkaline sand located on the coastline, a few feet above sea level.

The two soils in Texas were a heavy clay and a sand.

Soil samples in Puerto Rico were collected 2, 6, 13, and 26 wk. after treatment at depths of 0 to 6, 6 to 12, 21 to 27, 33 to 39, and 45 to 51 in. The samples were placed in 1-qt. styrene cups and transferred to the greenhouse for bioassay with cucumber plants. Subsamples were collected 3 and 6 mo. after treatment on plots that had been treated with 3 lb. per acre of picloram for analysis of residue levels by gas chromatography so that the chromatographic and biossay techniques could be compared. The samples for chromatographic analysis were frozen and then extracted and analyzed in accordance with procedures described previously.

Soil samples in Texas were collected from the surface 2 in. immediately after treatment and also 6, 13, 26, and 39 wk. after treatment. Soil samples were taken at depths of 0 to 6, 6 to 12, 12 to 24, 24 to 36, and 36 to 48 in. The soils were analyzed for picloram residues by gas chromatography.

Picloram at the lower two rates disappeared quite rapidly from the sandy soil in Texas (table 6.6). Picloram was detected to a depth of 24 to 36 in. 13 wk. after treatment, and to a depth of 36 to 48 in. 26 wk. after treatment for the 3-lb. rate. The residue levels were considerably higher for the 9-lb. rate, and when the last observation was made, picloram was distributed from 6 to 48 in. with the greatest amount being found in the 36- to 48-in. level.

Picloram was much less mobile in the clay soil of Texas. Thirty-nine weeks after treatment, the greatest residue level was found in the surface 0 to 6 in. of soil that had been treated with 9 lb. per acre of picloram. Small amounts of picloram had moved down to the 36- to 48-in. level, however.

The results in Puerto Rico paralled those in Texas. Six mo. after treatment, the highest concentration of picloram was found in the Fraternidad clay, followed by the Nipe clay, which is well-drained, and then the Catano sand. The residual concentration of picloram remaining in the soil 6 mo. after applying 9 lb. per acre of picloram ranged from 0.1 to 0.7 p.p.m. in the Fraternidad clay, 0.05 to 0.3 p.p.m. in the Nipe clay, and 0 to 0.001 in the Catano sand.

Most of the research on the movement and persistence of herbicides in soil was done with

TABLE 6.6.--Picloram residues in two Texas soils after application of 1, 3, and 9 lb. per acre

Picloram rate	Sample depth[1]	Picloram in two soils at specified weeks after treatment[2]									
		Clay					Sand				
		0	6	13	26	39	0	6	13	26	39
Lb. per acre	In.	P.p.m.									
1	0-6	2.29	--	0.15	0.02	0	1.45	0.03	0	0	0
	6-12		0	0	0	0		0.01	0	0	0
	12-24		0	0	0	0		0	0	0	0
	24-36		0	0	0	0		0	0	0	0
	36-48		0	0	0	0		0	0	0	0
3	0-6	6.34	0.11	0.67	0.15	0.03	5.26	0.11	0	0.02	0
	6-12		0	0	0.04	0.01		0	0.04	0	0
	12-24		0	0	0	0		0	0.07	0.05	0
	24-36		0	0	0	0		0	0.06	0.08	0.01
	36-48		0	0	0	0.01		0	0	0.01	0
9	0-6	20.15	4.09	0.33	0.22	0.16	20.37	0.19	0.07	0.03	0
	6-12		0.05	0.13	0.21	0.06		0.01	0.12	0.01	0.08
	12-24		0	0.05	0.08	0.02		0	0.23	0.05	0.05
	24-36		0	0.03	0.01	0.01		0	0	0.06	0.13
	36-48		0	0	0	0.01		0	0	0.06	0.22

[1] The sample taken immediately after treatment was only the surface 2 in. of soil.
[2] 0 time was immediately after treatment.

picloram. This was done advisedly, because it is known that the phenoxy herbicides are degraded rapidly in soils. Picloram is one of the best herbicides for defoliation and control of woody species, so its persistence and movement was of great importance. The research that has been conducted in Texas and Puerto Rico indicates that picloram is leached through the soil profile rapidly in sand, but more slowly in a heavy clay soil. Picloram is degraded rapidly by ultraviolet light. Thus, applications to the soil surface that are not followed by rain to leach the herbicide into the soil, will lose much of their effectiveness because of photo decomposition.

The data indicate that picloram will remain in the soil for relatively long periods of time. The rate of its disappearance from surface soils depends on the soil type and the amount of rainfall. There is little doubt that picloram applied at high rates to clay soils in areas having low rainfall would persist in phytotoxic quantities for long periods of time. We have evidence, however, (chapter 5) that revegetation occurred in the rain forest of Puerto Rico within 1 yr. after treatment with 27 lb. per acre of picloram. Picloram was still present in the lower levels of the soil profile, but had been sufficiently dissipated in the upper layers, where plant roots were actively absorbing, so that it was no longer phytotoxic.

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CHAPTER 7

EVALUATION OF HERBICIDES APPLIED TO FOLIAGE

The research reported in this chapter involves an evaluation of herbicides on a wide range of woody species in Texas and Puerto Rico. All of the treatments were applied to the foliage with several types of equipment.

Treatments in Texas were made at five locations (fig. 3.4) on a variety of woody species. The species were selected because previous work had shown them to be relatively resistant to phenoxy herbicides. In addition, they represented many plant families and genera so that a broad array of taxonomic entities was involved.

Research sites in Texas were located at Llano, Refugio, Victoria, Carlos, and Livingston. A description of the vegetation at each of the sites is given in chapter 3.

The treatments in Texas were applied with a contourmatic boom sprayer mounted on a 3/4-ton truck. The boom has three sections, each of which can be positioned hydraulically from controls on the truck. Research sites where the contourmatic boom sprayer was used were selected on the basis of brush density and growth low enough to permit treatment. Truck mobility on the research sites was aided by bulldozing lanes through the brush. Plots were then established on each side of the lanes. A plot width of 22 ft. was used for all treatments because that width could be effectively treated with the two end sections of the boom. Length of the plot was limited only by the total area available at each research site. Most of the plots were 95 ft. long, but some were as much as 200 ft. long. The contourmatic boom sprayer is shown in operation at one of the sites in figure 7.1.

Treatments in Puerto Rico were made in the Moist Coastal and Lower Cordillera Forests near Mayaguez (fig. 3.1). Most of the applications to guava were made with a portable compressed-air sprayer. For those treatments, volume per unit area could not be closely determined so the herbicidal rate was expressed in terms of pounds of herbicide per 100 gal. of spray solution.

Some of the treatments on guava and camasey, and all treatments on mango and pomarrosa were made with the telescoping pole sprayer described in chapter 11. Those treatments were applied at a rate and volume expressed in terms of pounds and gallons, respectively, per acre.

Research on vertical obscuration (chapter 10) showed that visibility of the ground from the air was not increased appreciably when the percentage of defoliation was less than 50 percent. That work was done in a Tropical Rain Forest having an upper canopy about 70 ft. above the ground. The effect of defoliation on vertical obscuration might be considerably different for a forest of shorter stature. However, in this chapter, acceptable percentages of defoliation will be based on levels of defoliation that are necessary in a tall forest, regardless of the stature of woody species that were actually treated.

For convenience of discussion, defoliation of 50 percent 1 or 2 wk. after treatment will be the minimum acceptable level. One year after treatment the minimum acceptable level of defoliation will be 70 percent. A lower percentage of defoliation at that time would mean that retreatment would soon be required to maintain a high level of vertical obscuration.

Figure 7.1.--The truck-mounted, contourmatic boom sprayer used for herbicidal treatments to the foliage in Texas.

Treatments in Texas

Whitebrush

Whitebrush occurs on about 6 million acres in the Edwards Plateau and the South Plains of Texas. It is commonly associated with other woody species, such as mesquite, Texas persimmon, tasajillo, and several species of oak and pricklypear cactus. Whitebrush, a member of the Verbenaceae, was chosen as one of the test species because it is relatively resistant to 2,4-D and 2,4,5-T. It sprouts readily from stems and the basal crown after treatment.

Whitebrush reaches a height of about 6 to 8 ft. and produces an enlarged basal crown just below the soil surface. In the Edwards Plateau whitebrush begins leafing out in early April, attains full leaf and flower the first 2 wk. in May, and then produces seed and drops its leaves during the hot, dry period of July and August. The phenologic cycle is repeated in the fall with full flowering and leaf production usually occurring during the first week of October.

McCully (8) recommended 1.25 lb. per acre of an amine of MCPA in 1 gal. of diesel oil and enough water to make 8 gal. of solution per acre for the control of whitebrush. He defined the optimum period of susceptibility as occurring when leaves had reached full size and the plants were in full flower. The most consistent results were obtained from fall treatments.

The test site for the research on whitebrush was located in the Edwards Plateau near Llano, Tex. The research was directed primarily toward an evaluation of many different herbicides for their effectiveness in defoliating and killing whitebrush, and secondarily toward a closer definition of the period of maximum susceptibility.

Test No. 1.--Fourteen herbicides at various rates were applied to whitebrush on July 30, 1963. A volume of 10 gal. per acre was applied on two plots for each treatment.

The time of treatment fell within the period when whitebrush normally drops its leaves. No rain had fallen during the 3 wk. before treatment and none fell for 10 days afterward. The plants were in a semi-dormant state with only a few leaves present on most plants.

Rapidity of defoliation could not be determined in this test because the plants had few leaves at the time of treatment. The first observation was made 8 wk. after treatment (table 7.1). The greatest herbicidal effect at this time was obtained from dicamba, 2,3,6-TBA, the ester of MCPA, 2,4,5-T:dicamba, and the higher rates of 2,4-D:2,4,5-T. Short-term defoliation obtained with diquat, paraquat, isocil, bromacil, DEF, isocil:paraquat, and the lowest rates of 2,4-D:2,4,5-T and the amine of MCPA was not acceptable.

Twenty-three weeks after treatment, the highest percentage of defoliation was obtained on plots treated with isocil and bromacil. The same was true 57 wk. after treatment, but isocil:paraquat and the highest rate of the ester of MCPA also provided acceptable defoliation. The same relative results were still apparent 101 weeks after treatment.

It is noteworthy that rapid defoliants such as diquat, paraquat, and DEF were particularly ineffective when treatments were made during the dormant season.

Isocil and bromacil killed almost all of the grasses and broadleaved herbaceous weeds, but established plants of sideoats grama were not affected. Mesquite, Texas persimmon, and various species of cactus and oak were not affected by the isocil and bromacil treatments.

Test No. 2.--Whitebrush was treated with 11 herbicides on October 1, 1963. Various herbicidal rates were evaluated but volume was constant at 5 gal. per acre. Two plots were sprayed for each treatment.

The leaves were full size and the plants in full flower at the time of spraying. About 1.3 in. of rain had fallen from September 1 to 10, but the weather was then dry until October 24, when 0.6 in. of rain fell. Rains were good in November.

TABLE 7.1.--The percentage defoliation of whitebrush resulting from treatments with 14 herbicides on July 30, 1963. All treatments were applied in a volume of 10 gal. per acre with a truck-mounted, contourmatic boom sprayer

Herbicide	Rate	Defoliation, weeks after treatment			
		8	23	57	101
	Lb. per acre	- - - -	Percent	- - - -	
Dicamba	4	60	20	1	0
	8	80	20	21	7
	12	80	50	55	43
Diquat	8	20	0	2	10
Paraquat	8	40	0	3	10
Paraquat:dicamba (1:1)	8	70	30	14	10
2,3,6-TBA	4	70	40	5	0
	8	70	60	32	18
	12	80	60	61	49
MCPA, amine	4	20	0	2	13
	8	50	30	41	37
	12	60	50	59	10
MCPA, ester	4	60	20	16	15
	8	80	50	43	47
	12	80	70	86	76
2,4,5-T, ester	4	50	10	5	12
	8	50	20	18	10
	12	70	20	9	27
2,4,5-T:dicamba (1:1)	8	80	40	33	28
2,4-D:2,4,5-T (1:1)	4	30	10	2	19
	8	80	40	24	26
	12	80	40	13	25
Isocil	2.5	0	40	4	15
	5	0	70	75	87
	10	0	90	98	100
Isocil:paraquat (4:5)	9	20	70	85	76
Bromacil	2.5	0	50	19	15
	5	0	30	95	45
	10	20	80	96	96
DEF	8	0	0	11	10
Untreated check	0	0	0	6	10

The amine of MCPA and dicamba:diquat caused the highest percentage of defoliation 1 wk. after treatment (table 7.2). The ester of MCPA and two rates of 2,4-D were also effective. Four weeks after treatment, defoliation was acceptable on most of the plots. Bromacil:diquat and 2,4,5-T:diquat were not effective treatments. Fifty-three wk. after treatment, defoliation greater than 70 percent was obtained on plots treated with one or more rates of dicamba, the ester of MCPA, picloram, 2,4-D:picloram, and 2,4-D. Only

TABLE 7.2.--The percentage defoliation of whitebrush resulting from treatments with 11 herbicides on October 1, 1963. All treatments were applied in a volume of 5 gal. per acre with a truck-mounted, controumatic boom sprayer

Herbicide	Rate	Defoliation, weeks after treatment				
		1	4	27	53	83
	Lb. per acre	- - - - - - Percent - - - - -				
Dicamba	1	40	60	50	20	30
	4	20	50	55	49	38
	8	40	80	90	82	67
Dicamba:diquat (4:1)	5	20	60	35	59	39
(2:1)	6	70	80	65	53	63
(1:1)	8	70	70	80	52	47
Diquat	1	50	40	5	3	10
	4	50	50	10	1	26
	8	30	60	35	3	19
MCPA, amine	1	60	90	80	55	33
	4	70	83	80	65	44
	8	70	70	60	42	40
MCPA, ester	1	50	90	90	76	55
	4	60	90	80	56	51
	8	50	100	90	74	71
Picloram	1	20	70	85	65	80
	2	10	40	80	97	75
	4	0	30	90	98	78
2,4-D:picloram (4:1)	1	40	80	55	74	37
	2	30	60	60	37	56
	4	40	80	90	82	62
2,4,5-T	1	30	70	75	53	3[illegible]
	4	50	90	85	65	57
	8	40	90	80	12	20
2,4,5-T:diquat (1:1)	8	30	40	35	5	11
2,4-D	1	60	80	65	49	50
	4	50	100	90	89	61
	8	40	100	90	80	49
Bromacil:diquat (5:4)	9	40	40	20	98	53
Untreated check	0	30	40	40	8	16

picloram provided an acceptable level of defoliation 83 wk. after treatment.

On the basis of short term defoliation, several herbicides provided acceptable results. The relatively low activity of diquat was disappointing, however. On the basis of long-term defoliation, picloram was unquestionably the most effective herbicide. Even 1 lb. of picloram provided more defoliation than 8 lb. of other herbicides.

Test No. 3.--Twelve herbicides were applied to whitebrush on May 11, 1964. The herbicides were evaluated at various rates but always in a constant volume of 10 gallons per acre. Two plots were treated for each treatment.

Leaves were full size and the plants in full flower at the time of treatment. Soil moisture was adequate for plant growth. About 4 in. of rain fell in April and about 1 in. on May 9. After treatment 2 in. of rain was recorded between May 18 and June 7.

Acceptable defoliation 1 wk. after treatment was obtained with all herbicides except bromacil and the lowest rate of 2,4,5-T. Six of the herbicides had caused 90 percent or more defoliation (table 7.3). Although not shown on the table, most of the plants that had been treated with paraquat lost most of their leaves from 2 to 4 days after treatment. Thus,

TABLE 7.3.--The percentage defoliation of whitebrush resulting from treatments with 12 herbicides on May 11, 1964. All treatments were applied in a volume of 10 gal. per acre with a truck-mounted, contourmatic boom sprayer

Herbicide	Rate	Defoliation, weeks after treatment				
		1	4	21	50	101
	Lb. per acre	- - - - -Percent - - - - -				
Paraquat	0.25	50	40	8	5	30
	0.50	82	65	7	9	29
	1	95	45	3	2	29
	4	90	30	3	0	37
	8	92	55	7	1	44
Dicamba:paraquat (1:1)	8	92	95	30	17	31
MCPA, amine	1	75	90	37	25	47
	4	92	100	85	76	67
	8	92	100	89	79	86
MCPA:paraquat (1:1)	8	90	100	41	5	35
Picloram	1	72	95	83	78	87
	2	70	100	92	87	83
	4	82	100	97	98	98
Picloram:paraquat (1:2)	6	90	100	88	88	90
Bromacil	5	15	45	62	42	41
2,4-D	1	60	60	17	26	51
	4	55	100	47	42	42
	8	60	100	76	56	47
2,4,5-T	1	30	90	50	16	58
	4	70	95	11	6	44
	8	75	100	15	14	54
2,4-D:2,4,5-T (1:1)	4	50	100	66	28	64
	8	50	100	69	42	43
2,4,5-T:paraquat (1:1)	8	92	75	5	5	43
2,4-D:picloram (4:1)	4	80	100	88	85	91
Untreated check	0	5	5	4	0	33

paraquat was the most rapid defoliant. Plants treated with paraquat refoliated rapidly, however, and 21 wk. after treatment virtually complete recovery had occurred.

Maximum defoliation was recorded 4 wk. after treatment for all herbicides except bromacil. Thereafter, whitebrush refoliated gradually on most of the plots. Fifty weeks after treatment, and at the end of the experimental period, only those plots treated with picloram, picloram:paraquat, and 2,4-D:picloram still had an acceptable percentage of defoliation. As was the case in the previous test, the highest percentage of whitebrush defoliation was obtained with picloram. In addition, picloram was also most toxic to Texas persimmon and to the various species of cactus present on the plots.

There is some suggestion that the rapidity of defoliation caused by picloram and 2,4,5-T was increased somewhat by the addition of paraquat, but the effect, if any, was slight. Long term defoliation was not affected by the addition of paraquat to various herbicides.

Test No. 4.--Nine herbicides were applied to whitebrush on October 7, 1964. The principle purpose of the study was to evaluate different ratios of MCPA:picloram and the effects of DMSO and ammonium thiocyanate as additives to MCPA. The herbicides were applied at a constant volume of 10 gal. per acre. Two plots were treated for each treatment.

There were few differences between treatments for both the short term and long term effects (table 7.4). None of the herbicides provided acceptable defoliation 1 week after treatment, but all did after 4 wk. All treatments except the 1:1 ratio of MCPA:2,4,5-T provided acceptable defoliation 75 wk. after treatment and defoliation was greater than 90 percent on all except three treatments.

The high percentage of defoliation for treatments in this experiment indicates that whitebrush was sprayed at a time when it was highly susceptible. Leaves were full size, plants in full flower, and there was excellent soil moisture at the time of treatment. About 9.7 in. of rain fell between September 3 and October 7. About 3.4 in. of rain was recorded during the 3 wk. after treatment.

Test No. 5.--Fourteen herbicides, mostly combinations, were applied to whitebrush on May 11, 1965. Various rates, as well as the effect of diesel oil in the spray solution, were evaluated. Two plots were sprayed for each treatment with a truck-mounted contourmatic boom sprayer in a volume of 10 gal. per acre.

TABLE 7.4.--The percentage defoliation of whitebrush resulting from treatments with nine herbicides on October 7, 1964. All treatments were applied in a volume of 10 gal. per acre with a truck-mounted, contourmatic boom sprayer

Herbicide	Rate	Defoliation, weeks after treatment			
		1	4	48	75
	Lb. per acre	- - - Percent - - - -			
MCPA	1	20	99	85	91
	2	20	100	95	93
	4	30	100	91	92
MCPA:picloram (1:2)	1.5	25	99	98	98
(1:2)	3	20	100	100	100
(1:1)	1	20	97	92	95
(1:1)	2	25	100	96	94
(1:1)	4	25	99	99	99
(1:3)	4	25	100	100	100
(2:1)	1.5	25	99	97	96
(2:1)	3	25	100	97	97
(3:1)	4	30	97	99	99
(4:1)	2.5	25	100	95	96
Picloram	1	17	100	99	99
	2	10	95	99	100
	3	10	70	100	100
	4	10	97	100	100
2,4-D:picloram (4:1)	2.5	20	99	97	95
MCPA:ammonium thiocyanate					
(1:.025)	1.025	15	100	90	93
(1:.05)	1.05	20	99	83	86
(1:1)	1.1	15	100	82	92
(1:2)	1.2	20	100	86	92
MCPA:DMSO (2:.01)	2.01	15	99	93	94
2,4-D	2	20	100	93	93
2,4-D:2,4,5-T (1:1)	4	15	98	81	88
MCPA:2,4,5-T (1:1)	1	10	51	60	63
(2:1)	1.5	25	100	90	94
Untreated check	0	0	10	35	29

The leaves were full size and plants in full flower at the time of treatment. There had been only 1 in. of rain in the 2 mo. preceding treatment, but about 3.1 in. fell in the week after treatment. An additional 2.1 in. fell within 1 mo. after treatment.

It was felt that adequate information had been developed on the rapidity of defoliation from various herbicides, so the plots in this test were not rated until 21 wk. after treatment (table 7.5). Most of the treatments provided a higher percentage of defoliation. Only

TABLE 7.5.--The percentage of whitebrush defoliation resulting from treatments with 14 herbicides on May 11, 1965. All treatments were applied in a volume of 10 gal. per acre with a truck-mounted, contourmatic boom sprayer

Herbicide	Rate	Diesel oil	Defoliation, weeks after treatment	
			21	49
	Lb. per acre	Gal.	- - -Percent - - -	
MCPA	1	0	94	92
	2	0	96	96
	1	1	93	94
	2	1	95	94
MCPA:ammonium thiocyanate (2:1)	1.5	0	94	94
MCPA:dicamba (1:1)	2	0	90	89
MCPA:2,4,5-T (2:1)	1.5	1	90	91
(4:1)	2.5	1	83	92
MCPA:picloram (1:1)	2	0	96	94
2,4-D:2,4,5-T (1:1)	8	1	87	93
2,4,5-T	0.5	1	65	30
2,4,5-T:ammonium thiocyanate (1:1)	1	1	33	30
Picloram	0.5	0	94	90
	1	0	98	98
	2	0	99	97
	2	1	100	100
	3	0	100	99
	4	0	100	100
	6	0	100	100
Picloram:paraquat (4:1)	5	0	100	100
Picloram:dicamba (1:1)	2	0	97	100
Picloram:ammonium thiocyanate (2:1)	1.5	0	98	98
Picloram:2,4,5-T (4:1)	2.5	1	100	100
Picloram:amitrole (1:2)	3	0	96	98
Untreated check	0	--	32	26

those plots treated with 2,4,5-T and 2,4,5-T: ammonium thiocyanate failed to provide acceptable defoliation 49 wk. after treatment. The remaining treatments gave such uniformly high defoliation that differences between treatments are not readily apparent. This test and the preceding one suggest that differences between treatments could probably be more easily defined if the spraying were done during a less than optimum period of susceptibility.

Test No. 6.--Five herbicides were applied at various rates to whitebrush on October 11, 1965. Two plots were treated for each treatment at a constant volume of 10 gal. per acre.

Leaves were full size and plants in full flower at the time of treatment. Information is not available regarding the availability of soil moisture but the whitebrush was in the proper phenologic stage for optimum susceptibility.

The results obtained from the herbicides were again remarkably uniform between treatments (table 7.6). All except one of the herbicidal treatments caused 90 percent or more defoliation. The herbicidal effect was good even from so low a rate as 0.5 lb. per acre of picloram.

Test No. 7.--The last foliage treatment on whitebrush was applied on May 20, 1966. In this test, the herbicidal rates were the same as those used in experiments on mixed brush in the Piney Woods of Texas and in the Rain Forest of Puerto Rico. The objective of the experiment was to compare promising herbicides with orange. Ideally, the herbicides used in this test would have been applied in volumes of 1.5, 3, and 6 gal. per acre of undiluted herbicide, as was done for the aerial tests in Puerto Rico and at Livingston, Tex. However, it was not possible to apply such low volumes with the contourmatic boom sprayer. Consequently, all treatments were applied at 6 gal.

TABLE 7.6.--The percentage defoliation of whitebrush resulting from treatments with five herbicides on October 11, 1965. All treatments were applied in a volume of 10 gal. per acre with a truck-mounted, contourmatic boom sprayer

Herbicide	Rate	Diesel oil	Defoliation 27 weeks after treatment
	Lb. per acre	Gal.	Percent
Picloram	0.5	0	93
	1	0	100
	2	0	100
	2	1	100
	3	0	100
	4	0	100
MCPA, amine	1	0	91
	1	1	86
	4	0	92
MCPA, ester	1	1	90
Picloram:MCPA (1:1)	2	0	100
Picloram:paraquat (1:1)	4	0	100
Untreated check	0	--	25

per acre. For the lower volumes, the herbicides were diluted with either diesel oil or water depending on their solubility characteristics. The herbicides were applied on two plots, at a time when leaves were full size and the plants in full flower.

The most rapid defoliation was obtained with paraquat (table 7.7). Two days after treatment more than 90 percent of the leaves had been killed and an average of 25 percent of the leaves had fallen from the plant. No other herbicide caused such a rapid plant response. One week after treatment, all herbicides had provided an acceptable level of defoliation. At the end of the experimental period, only the 3 lb. rate of paraquat failed to provide more than 70 percent defoliation.

The effects of the herbicides on the vegetation associated with whitebrush was essentially the same as that reported in earlier tests. Paraquat caused very rapid desiccation and defoliation of grasses, broadleaved forbs, and other woody plants. Orange, picloram, and M-2993 did not defoliate the associated vegetation as rapidly as did paraquat, but defoliation lasted for a longer period of time. Picloram was the only herbicide that caused severe injury to cactus.

Discussion of treatments on whitebrush.--The most rapid defoliation was consistently obtained with diquat and paraquat. The differences between these two herbicides were not great, but when all of the tests are considered, paraquat appears to be slightly more phytotoxic. Neither of the herbicides provided long term defoliation. Recovery usually started 2 or 3 mo. after treatment, and, at the end of a year, the effects of these herbicides were negligible.

Picloram was consistently the most effective herbicide for providing long term defoliation. Even a rate as low as 0.5 lb. per acre caused a high percentage of defoliation. In addition to its effect on whitebrush, picloram was phytotoxic to a wider range of herbaceous and woody species than any other herbicide. This is particularly true of the cactus species, which were not severely injured by any herbicide except picloram.

MCPA was the most effective of the phenoxy herbicides. A somewhat lower percentage of defoliation was obtained with 2,4-D, and 2,4,5-T was the poorest of the phenoxy herbicides that were tested. Even though MCPA caused as much defoliation as picloram in many cases, it did not provide as much bud suppression. Consequently, there was always a greater amount of lateral and basal sprout growth on plants that had been treated with MCPA than on those that had been treated with picloram.

Bromacil and isocil at 10 lb. per acre provided good control of whitebrush and a number of other woody species. Their control of grasses was outstanding.

TABLE 7.7.--The percentage defoliation of whitebrush resulting from treatments with four herbicides on May 20, 1966. All treatments were applied in a volume of 6 gal. per acre with a truck-mounted, contourmatic boom sprayer

Treatment			Diluent		Defoliation, weeks after treatment[1]				
Herbicide	Rate	Volume	Water	Diesel oil	2	7	13	27	96
	Lb. per acre	Gal. per acre	Gal.	Gal.	Percent				
Orange	12	1.5	0	4.5	85/10	100/95	100	100	98
	24	3.0	0	3.0	70/0	95/90	100	100	100
	48	6.0	0	0	75/10	98/90	100	100	100
Paraquat	3	1.5	4.5	0	93/25	95/90	100	85	60
	6	3.0	3.0	0	93/20	98/93	100	95	80
	12	6.0	0	0	93/30	100/83	100	100	98
Picloram	3	1.5	4.5	0	40/0	80/65	100	100	100
	6	3.0	3.0	0	50/5	95/90	100	100	100
	12	6.0	0	0	35/0	93/85	100	100	100
M-2993	7.5	1.5	0	4.5	35/0	93/85	100	100	100
	15	3.0	0	3.0	45/0	95/88	100	100	100
	30	6.0	0	0	65/10	98/85	100	100	100
Untreated check	0	--	--	--	10/10	15/15	10	25	30

[1] Where double figures are given, that to the left of the diagonal line represents defoliation plus dead leaves still on the plant; that to the right of the diagonal line represents defoliation only. Single figures represent defoliation with no dead leaves remaining on the plants.

Combinations of herbicides were not more effective than the better herbicides used alone. This does not mean, however, that herbicidal combinations are not useful. When the degree of control from a herbicide approaches 100 percent, little can be done to improve it. The utility of herbicidal combinations for the defoliation and control of whitebrush would have to be demonstrated with much lower rates than were used in the tests discussed in this chapter.

The time of application for the control of whitebrush is extremely important. For example, 1 lb. per acre of MCPA was an effective treatment if applied at a time when the leaves were full size, plants were in full flower, and there was adequate soil moisture for plant growth. Much higher rates had to be used at other times of the year when whitebrush was less susceptible.

The period of maximum susceptibility was much longer for picloram than for MCPA. Some applications of picloram in February and April were highly effective, but the best results were always obtained from treatments made in May and October. The greater timespan during which whitebrush can be controlled with picloram is highly important. The same principle has been observed on other woody species in Texas and in Puerto Rico. Treating with a herbicide that can be applied over a wider range of time reduces the probability of making applications during a period when the woody plants are not in a stage of high susceptibility.

In summary, paraquat was the most effective herbicide for rapid defoliation of whitebrush. Picloram was most effective for long term defoliation for three important reasons: (1) It caused the highest percentage of defoliation, (2) it was the most phytotoxic herbicide tested on the entire vegetational complex, and (3) the period of time during which plants are susceptible was greater for picloram than for any other herbicide.

Huisache and Mesquite

Huisache and mesquite are leguminous species widely distributed in the drier portions of subtropical and tropical America. They invade grassland areas rapidly and once established are difficult to control. Huisache and mesquite were chosen as test species because they represent a plant family that is widely distributed throughout the world. They are quite easily defoliated by phenoxy herbicides, but a high potential for lateral and basal sprouting make them difficult to kill.

Huisache was the species of primary interest. An effective method of extensive control had never been developed even though it is an aggressive invader and serious competitor on southwestern rangelands. The only recommended control measure for huisache was basal treatment of individual plants with 2,4,5-T in diesel oil (1).

A great deal of information was already available on the ecology and control of mesquite (4, 5, 9, 10, 12). Mesquite normally occurs with huisache, so data on its response were obtained to provide a wider range of information.

The test site for huisache-mesquite was located in the Gulf Prairie near Refugio, Tex. The herbicides were diluted in water and applied at a volume of 10 gal. per acre. Treatments for all tests were applied on duplicate plots at various times from October 1963 to June 1966. Ratings of the treated plots were made at frequent intervals after treatment to determine both the short term and long term effects of the herbicides.

Test No. 1.--The first test on the defoliation of huisache-mesquite was applied October 3, 1963. Nineteen herbicides and herbicidal combinations were tested at various rates.

Paraquat, diquat, and all herbicidal combinations that included paraquat or diquat gave excellent defoliation of both huisache and mesquite within 1 wk. after treatment (table 7.8). Effective defoliation 1 wk. after treatment was also found on plots that were treated with picloram and dicamba.

Differences in the response of huisache and mesquite to herbicides became apparent 1 or 2 yr. after treatment. Huisache appeared to be somewhat more susceptible to the herbicides tested than did mesquite. Fifty-two weeks after treatment, 11 herbicides at one or more rates had provided defoliation of 70 percent or more on huisache, but only 7 herbicides had done so on mesquite. However, 104 wk. post-treatment, defoliation of 70 percent or more was recorded for one or more rates of four herbicides on huisache and five herbicides on mesquite.

Picloram, bromacil, isocil, and picloram: diquat were most effective for long term

TABLE 7.8.--The percentage defoliation of huisache and mesquite resulting from treatments with 19 herbicides on October 3, 1963. All treatments were applied in a volume of 10 gal. per acre with a truck-mounted, contourmatic boom sprayer

Herbicide	Rate	Defoliation, weeks after treatment									
		Huisache					Mesquite				
		1	4	26	52	104	1	4	26	52	104
	Lb. per acre	- - - - - - -					Percent - - - - - - -				
Paraquat	2	100	100	63	40	--	100	80	60	85	--
	4	100	100	78	30	10	100	90	55	25	65
	8	100	100	80	70	30	100	80	73	90	83
Diquat	8	100	100	100	100	100	100	100	80	98	90
Picloram	1	100	100	100	100	20	60	100	--	--	10
	2	80	100	95	90	--	50	100	53	55	--
	4	90	100	95	100	100	100	90	78	75	25
2,4,5-T	4	60	80	75	50	0	40	100	75	60	0
	8	30	90	93	40	25	30	80	53	40	30
	12	30	100	93	30	15	40	100	70	30	10
2,4-D	4	40	70	85	15	0	30	70	53	10	0
	8	60	90	80	25	5	50	70	30	20	5
	12	50	100	80	35	0	60	100	70	40	0
Dicamba	4	80	100	98	65	--	60	100	60	60	--
	8	90	100	95	70	60	90	100	85	80	60
	12	90	100	100	93	50	90	100	65	--	--
Bromacil	2.5	0	70	40	55	15	20	30	8	0	15
	5	0	80	25	45	25	30	40	15	50	20
	10	0	80	35	98	100	20	70	5	50	60
Isocil	5	20	80	45	93	93	30	40	30	63	15
2,3,6-TBA	12	40	100	95	60	10	80	90	60	50	0
DEF	8	20	40	0	25	5	50	50	0	35	5
Paraquat:dicamba (1:1)	8	100	100	98	60	20	100	90	80	95	90
Paraquat:2,4,5-T (1:1)	8	100	100	88	80	10	100	80	70	50	80
Paraquat:bromacil (4:5)	9	100	90	55	95	--	100	90	25	50	--
2,4,5-T:ammonium thiocyanate (8:1)	4.5	20	80	90	20	0	30	70	40	20	10
2,4,5-T:DEF (1:2)	12	60	80	88	25	25	60	70	[illegible]	25	10
2,4,5-T:dicamba (1:1)	8	70	80	98	80	25	80	100	63	60	40
Picloram:diquat (1:8)	9	100	100	100	100	100	80	100	95	98	95
Picloram:2,4,5-T (1:4)	1	70	80	75	50	15	40	80	48	35	25
	2	90	100	100	60	25	60	100	40	70	30
Picloram:2,4-D (1:4)	4	90	100	95	75	40	60	100	70	55	40
Untreated check	0	0	20	3	23	0	7	13	0	30	0

defoliation of huisache. Paraquat, diquat, paraquat:dicamba, paraquat:2,4,5-T, and picloram:diquat were most effective for the control of mesquite. The long term effects of paraquat and diquat were surprising. DEF was the poorest herbicide tested on both species.

Test No. 2.--The second test involving the evaluation of herbicides for the defoliation of huisache and mesquite was applied on April 13, 1964. Eight herbicides were selected that had been effective in the first test. Ratings of the treated plots were made at intervals after treatment to determine both the short term and long term effects of the herbicides.

All of the herbicides provided good short term effects at one or more rates on both huisache and mesquite (table 7.9). The long

TABLE 7.9.--The percentage defoliation of huisache and mesquite resulting from treatments with eight herbicides on April 13, 1964. All treatments were applied in a volume of 10 gal. per acre with a truck-mounted, contourmatic boom sprayer

Herbicide	Rate	Defoliation, weeks after treatment									
		Huisache					Mesquite				
		1	4	26	52	104	1	4	26	52	104
	Lb. per acre	Percent									
Paraquat	4	100	99	35	40	25	100	99	93	95	90
	8	95	87	35	40	33	100	98	95	95	100
Picloram	1	93	100	15	20	18	93	100	80	60	40
	2	93	100	15	15	0	83	100	73	30	10
	4	100	100	45	68	25	98	100	88	80	65
2,4,5-T	2	88	100	15	20	20	100	100	95	95	95
	4	20	100	35	40	20	35	100	95	70	55
	8	58	100	45	40	18	73	100	95	100	55
Paraquat:bromacil (4:5)	9	100	99	45	78	55	100	100	83	90	90
Paraquat:dicamba (1:1)	8	95	90	25	40	28	95	99	97	93	85
Paraquat:2,4,5-T (1:1)	8	100	100	40	30	55	100	100	98	98	95
Paraquat:picloram (1:1)	8	100	100	10	25	0	100	100	97	99	98
2,4-D:2,4,5-T (1:1)	8	80	100	50	60	25	95	100	78	88	65
Untreated check	0	0	0	0	0	5	0	0	0	0	5

term effects were different from the results obtained in the first test in that mesquite was more susceptible to the herbicides than was huisache. One year after treatment, acceptable defoliation of huisache was obtained only with paraquat:bromacil; acceptable defoliation of mesquite was obtained with all treatments except the two lowest rates of picloram. Both species had recovered somewhat by the time of the 2 yr. rating, but the general response was the same.

Both rates of paraquat provided excellent long term defoliation of mesquite but not of huisache. In Test No. 1, the 4- and 8-lb. rates of paraquat provided only moderately good long term defoliation of mesquite and poor defoliation of huisache.

Test No. 3.--The third test on the defoliation of huisache and mesquite was applied on May 12, 1964. Four herbicides were evaluated at two rates. All plots except those treated with 4 lb. per acre of picloram were retreated on May 29, 1965.

All herbicides defoliated huisache satisfactorily within 1 week after treatment (table 7.10). One year after treatment, the defoliation of huisache was still high on plots treated with 4 lb. per acre of picloram, but considerable regrowth had occurred on all other plots. The retreatments on huisache again provided good short term defoliation, but none of the treatments except the higher rate of dicamba were more effective than the initial treatment.

Acceptable short term defoliation of mesquite was obtained with all herbicides except the lower rate of 2,4,5-T. Effectiveness persisted 52 wk. after treatment on all plots except those treated with the lower rates of paraquat, 2,4,5-T, and dicamba. Retreatments of mesquite were more effective than those on huisache. Acceptable defoliation was obtained with all retreatments on mesquite and the long term effects were improved. Fifty-two weeks after retreatment the lowest defoliation recorded was 80 percent.

Test No. 4.--Seven herbicides were evaluated for their effectiveness in defoliating huisache and mesquite on July 14, 1964. The objectives of the test were to evaluate somewhat lower rates than those used previously, and to extend the treatments to another season of the year. Ratings were made at periodic intervals after treatment.

All herbicides except 2,4,5-T and bromacil defoliated huisache rapidly (table 7.11).

TABLE 7.10.--The percentage defoliation of huisache and mesquite resulting from treatments with four herbicides on May 12, 1964. All treatments were applied in a volume of 10 gal. per acre with a truck-mounted contourmatic boom sprayer. All plots except those treated with 4 lb. per acre of picloram were retreated on May 29, 1965

Herbicide	Rate	Defoliation, weeks after treatment							
		Huisache				Mesquite			
		1	4	26	52	1	4	26	52
Treated May 12:	Lb. per acre	- - - - - -	- - - - - -	- - - - - -	- - - - - - Percent	- - - - - -	- - - - - -	- - - - - -	- - - - - -
Paraquat	1	50	50	0	0	100	100	60	30
	4	100	85	20	15	100	95	88	80
Picloram	1	100	99	55	45	70	100	85	80
	4	100	100	100	99	73	100	100	90
2,4,5-T	1	65	75	15	15	30	95	50	50
	4	60	98	55	35	70	100	90	70
Dicamba	1	95	97	40	40	70	50	10	20
	4	100	100	80	65	70	99	95	70
Untreated check		0	0	0	0	0	0	0	0
Retreated May 29:									
Paraquat	1	85	28	15	10	100	80	--	95
	4	95	90	15	15	100	98	--	100
Picloram	1	100	93	45	55	95	55	--	90
2,4,5-T	1	60	48	20	10	78	20	--	80
	4	85	98	65	25	83	55	--	83
Dicamba	1	95	93	45	20	60	70	--	80
	4	100	84	85	90	90	90	--	85
Untreated check	0	0	0	5	0	0	0	--	0

TABLE 7.11.--The percentage defoliation of huisache and mesquite resulting from treatments with seven herbicides on July 14, 1964. All treatments were applied in a volume of 10 gal. per acre with a truck-mounted, contourmatic boom sprayer

Herbicide	Rate	Defoliation, weeks after treatment							
		Huisache				Mesquite			
		1	4	13	52	1	4	13	52
	Lb. per acre	- - - - - -	- - - - - -	- - - - - -	- - - - - -Percent-	- - - - - -	- - - - - -	- - - - - -	- - - - - -
Paraquat	0.5	35	5	10	5	99	95	90	10
	2	85	15	5	30	99	85	50	30
Diquat	3	95	35	10	20	100	100	50	40
Picloram	0.5	100	90	40	30	80	80	40	20
	2	100	100	95	85	90	99	93	60
2,4,5-T	0.5	20	55	15	28	20	70	30	40
	2	30	90	75	35	60	97	85	40
Dicamba	2	100	100	90	60	95	98	70	60
Bromacil	10	35	70	75	100	35	70	45	30
Picloram:diquat (1:8)	4.5	98	65	25	15	100	100	70	20
Untreated check	0	0	0	0	0	0	0	0	0

However, plots treated with paraquat and diquat refoliated very rapidly, so that 4 wk. after treatment there was only a low percentage of defoliation. One year after treatment, bromacil was the most effective herbicide followed by picloram at 2 lb. per acre. Defoliation was less than 70 percent for all other treatments.

High levels of mesquite defoliation were recorded on all plots except those treated with bromacil and the lower rate of 2,4,5-T. The high initial defoliation was short-lived, however. Fifty-two weeks after treatment, defoliation was less than 70 percent on all plots.

The addition of diquat to picloram did not increase defoliation of huisache. One year after treatment 0.5 pound of picloram per acre had caused 30 percent defoliation of huisache, whereas the same rate of picloram in the picloram:diquat combination caused only 15 percent defoliation. On the other hand, the percentages of mesquite defoliation for picloram and picloram:diquat were the same 1 yr. after treatment. Paraquat and diquat used alone did not result in the good long term defoliation that was evident in earlier tests.

Test No. 5.--Five herbicides were evaluated for their effectiveness in defoliating huisache and mesquite on October 29, 1964.

All of the herbicides provided a high percentage defoliation of huisache 1 wk. after treatment (table 7.12). The plants on most plots recovered rapidly, however, so that 52 wk. after treatment 2 lb. per acre of picloram was the only treatment that provided acceptable defoliation.

On mesquite, all treatments except 2,4,5-T and the low rate of picloram provided a high percentage of defoliation 1 wk. after treatment. Plants on all of the plots recovered extensively, however. One year after treatment, the plots that had been treated with picloram had recovered completely, and the percentage of defoliation on other plots was far below an acceptable standard.

None of the treatments in this test were as effective as those applied in October 1963. The 1964 treatments were applied almost a month later in the year than those applied in 1963, which may have influenced the results. All of the reasons for the differences between the 2 years are not evident, however.

Test No. 6.--Five herbicides were evaluated in the sixth test for the defoliation of huisache and mesquite. The treatments were applied May 29, 1965.

All of the herbicides provided a high percentage of defoliation of huisache 1 wk. after treatment. Recovery occurred on most of the plots, however, so that 1 yr. after treatment, only picloram and picloram:2,4,5-T at 2 lb. per acre provided an acceptable percentage of defoliation.

The initial response of mesquite was similar to that of huisache (table 7.13). One year after treatment only 2,4,5-T and the lower rate of picloram failed to provide an acceptable level of defoliation. In this test, the addition of paraquat to picloram gave a higher percentage of mesquite control than did picloram alone, but an opposite effect was evident on huisache. Similar results were obtained from treatments made in July 1964.

Test No. 7.--Picloram at 1, 2, and 3 lb. per acre, 2,4,5-T at 2 lb. per acre, and picloram: 2,4,5-T (1:1) at 2 lb. per acre were evaluated on huisache and mesquite on June 15, 1966. The initial response from these herbicides was essentially the same as that reported for earlier treatments. Since the long term effects are not yet available, the tabular summation of the data is not given.

Discussion of treatments on huisache and mesquite.--We tested 21 herbicides for their effectiveness in defoliating huisache and mesquite. The herbicides were applied at rates ranging from 1/2 to 12 lb. per acre on seven dates starting in October 1963 and ending in June 1966. Ratings were made 1, 4, 13, 26, 52, and 104 wk. after treatment.

Most of the herbicides defoliated huisache quite rapidly. Bromacil, isocil, DEF, 2,4-D, and 2,4,5-T were the only herbicides that did not cause a high percentage of defoliation 1 wk. after treatment. Good long term defoliation was obtained with many herbicides including the 2- and 4-lb. per acre rates of picloram, one treatment with 8 lb. of diquat, 10 lb. of bromacil, 5 lb. of isocil, a picloram: diquat combination, and a paraquat:bromacil combination. Picloram was the best overall herbicide in terms of rapidity of defoliation and long term defoliation. About 2 lb. per acre was needed to give a lasting effect. Huisache appeared to be more susceptible from May

TABLE 7.12.--The percentage defoliation of huisache and mesquite resulting from treatments with five herbicides on October 29, 1964. All treatments were applied in a volume of 10 gal. per acre with a truck-mounted, contourmatic boom sprayer

Herbicide	Rate	Defoliation, weeks after treatment							
		Huisache				Mesquite			
		1	4	26	52	1	4	26	52
	Lb. per acre	Percent							
Paraquat	2	85	99	35	10	100	98	10	20
Diquat	8	100	100	93	55	100	99	50	40
Picloram	1	100	100	90	60	35	97	15	0
	2	100	100	99	95	90	100	15	0
2,4,5-T	2	70	99	88	40	45	99	15	40
Picloram:paraquat (1:1)	2	100	100	94	40	100	100	10	15
Untreated check	0	0	0	0	0	0	0	0	0

TABLE 7.13.--The percentage defoliation of huisache and mesquite resulting from treatments with five herbicides on May 29, 1965. All treatments were applied in a volume of 10 gal. per acre with a truck-mounted, contourmatic boom sprayer

Herbicide	Rate	Defoliation, weeks after treatment							
		Huisache				Mesquite			
		1	4	26	52	1	4	26	52
	Lb. per acre	Percent							
Paraquat	2	95	65	25	5	100	68	--	95
Picloram	1	99	98	60	73	93	68	--	35
	2	100	100	95	95	95	93	--	88
2,4,5-T	2	85	93	15	25	73	50	--	50
Picloram:paraquat (1:1)	2	99	95	55	20	100	100	--	80
Picloram:2,4,5-T (1:1)	2	100	100	99	93	88	98	--	90
Untreated check	0	0	40	0	5	0	8	--	5

through October; treatments made in April were definitely less effective.

Mesquite was defoliated most rapidly by picloram, paraquat, and diquat, and by combinations containing any one of the three herbicides. Rapidity of defoliation did not appear to be related to the time of treatment. Good long term defoliation was obtained with 2,4,5-T, some of the picloram treatments, some of the paraquat treatments, and some combinations containing any two of the three herbicides mentioned above. Mesquite is known to be susceptible to 2,4,5-T if applications are made at the proper stage of development. The period of maximum susceptibility to 2,4,5-T occurs in the spring about 40 to 90 days after the trees have leafed out. It is extremely interesting to see that paraquat provided long term defoliation when treatments were made in April, May, and October. Mesquite is the only species that responded to paraquat so well, but some kill of live oak and yaupon was also obtained with high rates of paraquat.

Yaupon, Winged Elm, and Oak Species

Yaupon, winged elm, and oaks are a common association in the Post Oak Savannah. The three species, which are representatives of three plant families, are relatively resistant to most herbicides. Thus, the association is a good one in which to work because herbicides effective for controlling these three species would also be expected to be effective on many other woody species.

Post oak and blackjack oak are the dominant species in the Post Oak Savannah. They commonly grow to height of 40 ft. and are frequently taller. They are distributed on about 8 million acres in the Post Oak Savannah and also occur in the East and West Cross Timbers.

The control of post oak and blackjack oak has received considerable attention over a span of many years. Acceptable control can be obtained with broadcast applications of herbicides to the foliage or to the soil, and with single-stem treatments. Elwell (3) recommended aerial treatments in Oklahoma with 2 lb. per acre of 2,4,5-T in consecutive years. A similar recommendation was made in Texas (1). Treatments were most effective when applications were made shortly after the leaves had reached full size. That period usually occurs from May 15 to July 15 in Oklahoma and probably a little earlier in the central portions of Texas. Poor control was obtained from applications made when the leaves were less than full size, or as late as August or September.

The oak species can also be controlled with fenuron applied to the soil as a pelleted formulation (2). Good control was obtained with 4 lb. of the active ingredient per acre. The effectiveness of fenuron was greater on sandy soils than on heavy loam or clay soils.

Winged elm occurs as a sub-dominant in the Post Oak Savannah of Texas on approximately 2.5 million acres of rangeland. It is widely distributed throughout the southern part of the Eastern Deciduous Forest and Tall Grass Prairie. It reaches a stature of 40 ft. or more and forms a portion of the upper canopy, together with post and blackjack oak.

Winged elm is a difficult species to control. The recommended foliage treatments for the control of post oak and blackjack oak have little effect on winged elm. Basal treatments on individual stems are effective but are time consuming and costly.

Yaupon is a common understory species in the Post Oak Savannah. It may reach a height of 65 ft. but is usually shorter. Darrow and McCully (2) found it was less susceptible to fenuron than the oaks. Little work had been done on the control of this species by foliage application of herbicides, so there was no recommended method of control.

The principle test site for the oak-winged elm-yaupon association was near Carlos, Tex. Some work, particularly on winged elm, was also done near Edge, Tex.

During the course of the study, applications were made on duplicate plots in July 1963; October 1963; April, June, and October 1964, and in May 1965. The treated plots were rated at intervals of 1, 4, 26, 52, and 104 wk. after treatment whenever possible. Some of the rating dates fell within the winter period when the plants were normally defoliated, so an estimate of the defoliation caused by the herbicides was not possible.

Test No. 1.--The first test was applied in July 1963. Eleven herbicides were evaluated for their effectiveness in defoliating the test species.

Paraquat was the only herbicide that caused more than 50 percent defoliation 1 wk. after treatment, but 4 wk. post-treatment defoliation exceeded 50 percent on most of the plots (table 7.14). The most effective long term defoliants were isocil, bromacil, and paraquat:isocil. Paraquat enhanced the activity of isocil for both short term and long term effects, but did not enhance the long term activity of 2,4,5-T and it appeared to be inhibitory for the short term effect.

Winged elm was defoliated most rapidly by paraquat and paraquat:isocil, and the highest rate of 2,4,5-T. None gave effective long term defoliation. Two years after treatment, 10 lb. per acre of bromacil had provided a defoliation of only 25 percent. All other treatments were even less effective.

Acceptable defoliation of oak 1 wk. after treatment was obtained with paraquat:isocil and the highest rates of paraquat and 2,3,6-TBA. One and two years after treatment only 10 lb. per acre of isocil and bromacil were effective. All other treatments were decidedly inferior.

Test No. 2.--Six herbicides were evaluated in October 1963 for their effectiveness in defoliating yaupon, winged elm, and oak species. The treatments were applied just before the start of the dormant season so the rapidity of defoliation could not be observed.

TABLE 7.14.--The percentage defoliation of yaupon, winged elm, and oak species resulting from treatments with 11 herbicides in July 1963. All herbicides were applied in a volume of 10 gal. per acre with a truck-mounted, contourmatic boom sprayer

Herbicide	Rate	Defoliation, weeks after treatment														
		Yaupon					Winged elm					Oaks				
		1	4	26	52	104	1	4	26	52	104	1	4	26	52	104
	Lb. per acre	Percent														
2,4,5-T	4	8	63	--	55	33	35	85	--	18	0	38	70	--	25	5
	8	15	63	--	60	45	15	63	--	20	13	15	63	--	30	18
	12	15	74	--	70	45	50	85	30	--	5	38	80	--	20	3
2,3,6-TBA	4	8	38	--	40	18	25	63	--	20	0	20	40	--	10	3
	8	15	51	--	35	15	25	85	--	20	10	20	63	--	15	5
	12	8	50	--	63	40	38	70	--	30	13	50	38	--	20	8
Dicamba	4	0	63	--	50	28	15	85	--	15	0	15	65	--	10	5
	8	3	63	--	75	60	15	85	--	20	10	15	65	--	55	8
	12	15	74	--	78	58	25	85	--	40	20	15	74	--	--	13
Diquat	2	15	27	--	78	3	25	48	--	10	3	25	38	--	10	3
	4	27	63	--	--	10	38	63	--	15	3	38	63	--	20	3
	8	38	51	--	--	8	38	38	--	10	0	38	55	--	0	0
Paraquat	2	2	38	--	15	3	45	45	--	10	0	38	63	--	10	0
	4	51	38	--	25	8	63	63	--	10	3	50	65	--	10	0
	8	51	74	--	40	13	63	85	--	10	0	60	85	--	20	3
Isocil	2.5	0	63	--	68	55	0	15	--	20	5	4	85	--	50	25
	5	0	63	--	88	85	15	38	--	10	3	10	85	--	40	8
	10	0	63	--	90	95	0	85	--	30	8	11	85	--	90	70
Bromacil	2.5	0	63	--	43	8	10	63	--	10	8	10	85	--	10	0
	5	0	63	--	63	60	10	63	--	20	3	4	85	--	58	8
	1	0	63	--	94	93	0	63	--	60	25	4	85	--	83	75
2,4-D:2,4,5-T (1:1)	4	15	63	--	45	30	25	85	--	15	8	10	65	--	20	8
	8	10	70	--	50	45	25	85	--	15	5	15	85	--	20	5
	12	15	70	--	68	45	25	85	--	40	13	17	70	--	35	3
2,4,5-T:dicamba (1:1)	8	10	70	--	65	65	25	85	--	35	10	15	80	--	40	20
Dicamba:paraquat (1:1)	8	38	63	--	65	22	45	85	--	10	5	38	85	--	15	3
Paraquat:isocil (4:5)	9	45	63	--	95	98	63	70	--	10	5	63	85	--	40	30

A defoliation of 80 percent was recorded on plots treated with dicamba 1 yr. after treatment (table 7.15). Two years after treatment, defoliation was only 60 percent. The other treatments on yaupon and all of the treatments on winged elm and the oak species were ineffective. October is unquestionably a poor season for treating these species.

Test No. 3.--Eleven herbicides were evaluated in April 1964 for their effectiveness in defoliating yaupon, winged elm, and various species of oak.

Paraquat and any combination of herbicides that included paraquat defoliated yaupon most effectively (table 7.16). Yaupon on most of the plots recovered quite rapidly, however. One year after treatment, defoliation greater than 70 percent was recorded for plots treated with one or more rates of 2,4,5-T, bromacil, picloram, paraquat:bromacil, and paraquat: picloram. Two years after treatment, defoliation greater than 70 percent was obtained only on plots treated with bromacil, paraquat: picloram, and the highest rate of picloram.

Only the 2 lb. rate of 2,4,5-T provided an acceptable degree of defoliation of winged elm 1 wk. after treatment. One year after treatment, plots treated with 2 lb. of 2,4,5-T and 8 lb. of picloram and paraquat:picloram had 100 percent defoliation. All other treatments were much less effective. Two years after treatment, the only plots still having 100 percent defoliation were those treated with 8 lb. per acre of picloram.

TABLE 7.15.--The percentage defoliation of yaupon, winged elm, and oak species resulting from treatments with six herbicides in October 1963. All herbicides were applied in a volume of 10 gal. per acre with a truck-mounted, contourmatic boom sprayer

Herbicide	Rate	Defoliation, weeks after treatment								
		Yaupon			Winged elm			Oaks		
		26	52	104	26	52	104	26	52	104
	Lb. per acre	Percent								
2,4,5-T	8	88	68	38	18	--	0	--	20	3
Dicamba	8	88	80	60	35	--	8	--	15	8
Paraquat	8	63	45	15	20	--	3	--	20	10
2,4,5-T:paraquat (1:2)	12	--	--	13	--	--	8	--	--	20
Dicamba:paraquat (1:1)	8	--	40	22	--	--	3	--	40	5
Paraquat:bromacil (4:5)	9	--	63	45	--	--	0	--	20	5

TABLE 7.16.--The percentage defoliation of yaupon, winged elm, and oak species resulting from treatments with 11 herbicides in April 1964. All herbicides were applied in a volume of 10 gal. per acre with a truck-mounted, contourmatic boom sprayer

Herbicide	Rate	Defoliation, weeks after treatment														
		Yaupon					Winged elm					Oaks				
		1	4	26	52	104	1	4	26	52	104	1	4	26	52	104
	Lb. per acre	Percent														
2,4,5-T	2	10	73	91	83	46	53	55	80	100	60	5	58	89	100	90
	8	5	88	83	48	29	23	93	70	13	20	5	88	84	53	30
Fenuron	5	3	43	43	3	0	5	35	50	0	--	0	65	80	13	0
Dicamba	4	63	75	60	25	15	35	35	70	10	5	98	50	59	25	20
Bromacil	5	5	65	90	90	70	0	55	95	5	0	10	58	72	85	15
Paraquat	4	83	85	55	23	10	23	30	48	10	5	18	50	59	18	5
	8	79	75	64	40	10	33	55	58	13	--	60	70	75	45	15
Picloram	1	0	25	38	8	5	0	45	20	0	0	5	15	39	8	10
	4	3	54	80	50	40	10	95	89	33	25	3	75	92	50	40
	8	8	73	98	100	100	28	95	97	100	100	15	78	97	95	95
2,4-D:2,4,5-T (1:1)	8	5	93	82	58	48	30	90	65	23	10	13	85	78	68	20
2,4,5-T:paraquat (1:2)	12	78	87	65	38	25	35	74	62	9	7	65	75	75	11	10
Dicamba:paraquat (1:1)	8	78	75	77	45	15	15	50	53	20	5	60	60	74	35	10
Paraquat:bromacil (4:5)	9	78	85	83	70	55	40	33	53	30	20	80	75	78	88	60
Paraquat:picloram (1:1)	8	73	93	97	100	100	35	60	99	100	--	68	88	97	100	100

The oak species were defoliated rapidly by the higher rate of paraquat and all combinations containing paraquat. One year after treatment, one or more rates of 2,4,5-T, bromacil, picloram, paraquat:bromacil, and paraquat:picloram had provided defoliation of oak greater than 70 percent. Two years after treatment, however, only 2,4,5-T, picloram, and paraquat:picloram could still be listed in that category. The paraquat:picloram combination was particularly effective.

Test No. 4.--A duplicate of the April 1964 experiment was applied in June 1964. Identical herbicides and rates of applications were used.

In this test acceptable defoliation of yaupon within 1 wk. after treatment was obtained with one or more rates of 2,4,5,-T, paraquat, 2,4,5-T:paraquat, dicamba:paraquat, and paraquat:bromacil (table 7.17). One year after treatment, defoliation of 70 percent or more was obtained with 2,4,5-T, paraquat:bromacil, and paraquat:picloram. Two years after treatment, only those plots treated with paraquat: picloram still had a defoliation exceeding 70 percent.

Winged elm responded more rapidly to most of the herbicides in the June test than in the April test. One year after treatment, acceptable defoliation was obtained only on plots treated with paraquat:picloram. Two years after treatment, the highest rate of picloram was effective, but defoliation was not recorded on plots treated with paraquat:picloram.

Defoliation of the oak species also took place slowly. Only five of the treatments provided acceptable defoliation 1 wk. after treatment. One year after treatment, 2,4,5-T and paraquat:picloram were the only effective herbicides. The same relationship still held 2 yr. after treatment.

Test No. 5.--Five herbicides that had shown promise for the control of yaupon, winged elm, and oak species were tested again in October 1964.

The highest percent of defoliation 1 wk. after treatment was obtained with paraquat, but that was only 33 percent (table 7.18). Bromacil and the two higher rates of picloram were the best treatments 1 yr. after treatment. Two years after treatment, the highest rate of picloram was unquestionably the most effective herbicide, but the results obtained with bromacil and the 5-lb. rate of picloram were also acceptable.

Acceptable initial defoliation of winged elm was obtained with all herbicides in this test, but that obtained with paraquat was particularly good. Only fragmentary data are available for subsequent ratings, but bromacil and the highest rate of picloram were acceptable treatments at the end of 2 yr.

The rapidity of defoliation of the oak species was not determined. The only acceptable treatment for the defoliation of these species 1 and 2 yr. after treatment was the highest rate of picloram.

Test No. 6.--The last treatments on yaupon, winged elm, and the oak species were applied

TABLE 7.17.--The percentage defoliation of yaupon, winged elm, and oak species resulting from treatments with 11 herbicides in June 1964. All herbicides were applied in a volume of 10 gal. per acre with a truck-mounted, contourmatic boom aprayer

Herbicide	Rate	Defoliation, weeks after treatment														
		Yaupon					Winged elm					Oaks				
		1	4	26	52	104	1	4	26	52	104	1	4	26	52	104
	Lb. per acre	Percent														
2,4,5-T	2	10	80	--	78	42	65	85	--	13	15	5	58	--	83	60
	8	65	93	--	83	40	60	100	--	20	10	60	83	--	78	80
Fenuron	5	20	60	--	3	5	25	70	--	--	--	38	85	--	3	5
Dicamba	4	10	85	--	35	10	60	85	--	15	5	15	70	--	5	10
Bromacil	5	10	88	--	13	27	43	80	--	3	5	38	87	--	5	5
Paraquat	4	70	83	--	18	5	25	60	--	--	--	60	83	--	15	10
	8	50	78	--	20	15	55	80	--	3	--	55	78	--	13	5
Picloram	1	13	80	--	35	30	28	85	--	10	5	5	75	--	30	20
	4	18	80	--	58	35	33	86	--	58	50	43	--	--	48	25
	8	13	82	--	59	65	50	89	--	50	80	13	82	--	65	60
2,4-D:2,4,5-T (1:1)	8	25	90	--	55	27	33	93	--	20	5	15	88	--	58	20
2,4,5-T:paraquat (1:2)	12	67	89	--	65	40	47	95	--	17	5	55	84	--	58	25
Dicamba:paraquat (1:1)	8	55	85	--	50	10	60	85	--	13	0	60	85	--	33	4
Paraquat:bromacil (4:5)	9	83	85	--	73	40	50	87	--	23	16	70	70	--	50	15
Paraquat:picloram (1:1)	8	45	85	--	93	85	45	85	--	100	--	35	80	--	78	85

TABLE 7.18.--The percentage defoliation of yaupon, winged elm, and oak apeciea reaulting from treatmenta with five herbicidea in October 1964. All herbicidea were applied in a volume of 10 gal. per acre with a truck-mounted, contourmatic boom sprayer

Herbicide	Rate	Defoliation, weeks after treatment														
		Yaupon					Winged elm					Oaka				
		1	4	26	52	104	1	4	26	52	104	1	4	26	52	104
	Lb. per acre	Percent														
2,4,5-T	2	3	30	40	20	5	75	--	8	--	5	--	--	20	8	5
	8	5	75	78	60	10	60	--	10	5	5	--	--	40	18	5
Dicamba	2	5	20	10	8	10	60	--	10	5	--	--	--	23	10	--
	8	0	40	80	28	35	65	--	10	--	--	--	--	25	20	20
Bromacil	5	3	45	70	93	75	50	--	8	25	70	--	--	25	45	30
Paraquat	8	33	61	23	10	5	95	--	3	--	--	--	--	15	8	0
Picloram	2	0	20	25	18	10	60	--	0	0	0	--	--	23	15	15
	5	3	45	70	85	70	55	--	70	50	45	--	--	68	58	50
	8	0	75	98	100	100	75	--	100	80	70	--	--	78	100	100

TABLE 7.19.--The percentage defoliation of yaupon, winged elm, and oak speciea resulting from treatment with four herbicides in May 1965. All herbicidea were applied in a volume of 10 gal. per acre with a truck-mounted, contourmatic boom sprayer

Herbicide	Rate	Defoliation, weeks after treatment											
		Yaupon				Winged elm				Oaks			
		1	4	26	52	1	4	26	52	1	4	26	52
	Lb. per acre	Percent											
Paraquat	4	68	55	--	10	48	33	--	10	55	68	--	10
	8	73	63	--	20	38	35	--	20	70	73	--	3
Picloram	4	70	78	--	70	45	63	--	60	55	70	--	50
	8	10	95	--	100	65	100	--	100	13	93	--	100
2,4-D:2,4,5-T (1:1)	8	33	88	--	60	35	83	--	15	35	88	--	50
Paraquat:picloram (1:1)	8	43	98	--	100	45	100	--	100	48	85	--	90
(2:1)	6	78	98	--	100	85	100	--	--	48	88	--	100

in May 1965. Four herbicides were tested that had given good results in previous treatments.

The initial and long term effects on yaupon were essentially the same as in previous treatments (table 7.19). Picloram and paraquat: picloram provided excellent control 1 yr. after treatment.

The same herbicides that were effective for the defoliation of yaupon were also most effective on winged elm and the oak species. The spring treatment date is most desirable for all the woody species in this vegetational association.

Discussion of treatments on yaupon, winged elm, and oak species.--The best short term defoliation of yaupon was obtained from treatments made during the spring and summer seasons. Paraquat and combinations of herbicides including paraquat were most effective for that purpose. The best long term defoliation occurred on plots treated with picloram, paraquat:picloram, or bromacil. The percentage of defoliation was low on plots treated with other herbicides and the plants recovered rapidly. Long term defoliation of yaupon was best obtained with 8 lb. of picloram. However, the amount of the picloram could be reduced if paraquat was added to the spray solution. A 1:1 ratio of paraquat:picloram at 8 lb. per acre was as good as 8 lb. per acre of picloram used alone. A 2:1 ratio of paraquat:picloram at 6 lb. per acre was just as effective as a 1:1 ratio at 8 lb. per acre.

Acceptable defoliation of winged elm 1 wk. after treatment was obtained with most herbicides on one date or another. The highest percentages of initial defoliation were obtained from treatments made in October. Picloram and paraquat:picloram provided the best long term effects. At least 8 lb. per acre of either herbicide was necessary to provide high defoliation for extended periods. Winged elm is probably the most resistant species in Texas on which herbicides were evaluated.

The most rapid defoliation of oak species was obtained with paraquat or herbicidal combinations containing paraquat. Picloram and paraquat:picloram gave the best long term effects. Eight pounds per acre was necessary to maintain good control 2 yr. after treatment. Other herbicides were considerably less effective.

Herbicides for the control of all woody species in the yaupon-winged elm-oak association must be applied at relatively high rates for effective control. Eight pounds per acre of picloram, 8 lb. of a 1:1 ratio of paraquat: picloram, and 6 lb. of a 2:1 ratio of paraquat: picloram all gave good control of the woody plants in this vegetational association. The paraquat:picloram combination is preferred because plants defoliate more rapidly and less herbicide is needed. The addition of paraquat to picloram also reduces the cost of the treatment since paraquat costs only about three-fourths as much as does picloram.

All of the woody species discussed in this section were most susceptible to the herbicides when applied during the spring or summer. October treatments were much less effective.

The treatments made in April and June 1964 provide valuable data on the effect of adding paraquat to other herbicides. In those tests, paraquat was added to 2,4,5-T, dicamba, bromacil, and picloram. The results obtained on the two treatment dates, in terms of long-term defoliation, were in close agreement. The activity of 2,4,5-T was not affected or was slightly reduced by the addition of paraquat. The same was true of dicamba. The activity of bromacil and picloram, on the other hand, was enhanced by the addition of paraquat. It may be remembered that paraquat did not enhance the activity of picloram on whitebrush and the same was true on live oak and huisache. Whether the differential effects are due to inherent characteristics of the chemicals or to plant species is not known.

Live oak

Live oak is an evergreen species that ranges from a low-growing shrub to massive trees. It occurs on several million acres of rangelands in Texas. Live oak has the potential for rapid invasion of grazing lands, where it forms dense thickets with a concurrent decrease in the amount of grass. Live oak makes most of its growth during the spring season when there is enough rainfall to provide adequate soil moisture for plant growth.

A method of control for live oak had not been developed when the ARPA project was initiated. A few exploratory tests indicated the species was difficult to control with herbicides and mechanical methods would be extremely expensive. Individual plant treatments with 2,4,5-T applied to frills, stumps, or stem bases were recommended (1), but such a treatment would be too expensive and time-consuming for extensive operations.

The test site for herbicidal treatments to live oak was near Victoria, Tex.

Live oak was treated in August and October 1963; April, May, July, August, and October 1964; and in June 1965. All treatments were applied with a contourmatic boom sprayer mounted on a 3/4-ton truck. Plots treated in August 1963 were 22 by 200 ft., but the size of the plots for all later treatments was 22 by 95 ft. Two replications were used in a randomized block design.

Most of the herbicides were applied in a volume of 10 gal. per acre with water as the diluent. Herbicides formulated as wettable powders were applied in a volume of 20 gal. per acre.

The treated plots were rated at periodic intervals after treament. The percentage of defoliation was visually estimated for each plot and averaged to provide a treatment mean.

Test No. 1.--Fifteen herbicides were evaluated for their effectiveness in defoliating live oak on August 24, 1964.

Acceptable percentages of defoliation 1 week after treatment were obtained with five herbicides (table 7.20). Paraquat and diquat were

TABLE 7.20.--The percentage defoliation of live oak resulting from treatments with 15 herbicides applied August 12, 1963, and retreatments of the same plots on August 24, 1964. All treatments were applied in a volume of 10 gal. per acre, with a truck-mounted, contourmatic boom sprayer

Herbicide	Rate	Defoliation, weeks after treatment				
		1	4	26	52	104
	Lb. per acre	- - - -	-	Percent	-	- - - -
Paraquat	2	60	60	70	35	18
	4	70	80	90	40	--
	8	60	70	90	35	13
Diquat	2	50	50	60	8	20
	4	60	40	65	13	20
	8	70	70	65	3	20
2,4,5-T	4	40	70	100	55	--
	8	30	70	95	68	33
	12	40	70	100	78	28
Dicamba	4	20	50	85	58	--
	8	20	50	80	40	13
	12	30	60	100	60	40
Bromacil	2.5	0	60	100	35	20
	5	20	60	100	95	88
	10	0	80	100	100	100
Isocil	2.5	20	60	95	34	37
	5	20	80	100	90	95
	10	10	60	100	99	100
Fenuron	5	0	40	65	5	3
2,3,6-TBA	4	20	50	45	25	3
	8	20	30	20	10	3
	12	40	50	75	58	18
DEF	2	10	20	5	5	0
	4	20	30	45	15	13
	8	10	50	15	10	5
Paraquat:dicamba (1:1)	8	60	80	95	78	--
Paraquat:bromacil (4:5)	9	60	80	100	85	--
2,4,5-T:dicamba (1:1)	8	60	80	100	73	33
2,4,5-T:ammonium thiocyanate (8:1)	4.5	40	60	95	55	18
2,4,5-T:DEF (1:1)	8	20	50	90	70	33
2,4,5-T:2,4-D (1:1)	4	10	60	80	40	--
	8	20	60	95	58	20
	12	40	80	100	73	35
Untreated check	0	0	10	5	0	3
Retreatments						
Paraquat	4	68	97	99	80	25
2,4,5-T	4	38	94	97	70	40
Dicamba	4	10	75	93	55	35
Paraquat:dicamba (1:1)	4	65	93	99	85	70
Paraquat:bromacil (4:5)	4.5	85	99	100	95	75
2,4,5-T:2,4-D (1:1)	4	33	93	97	70	30

effective. The maximum defoliation occurred almost invariably 26 wk. after treatment. Thereafter, the plants refoliated to a greater or lesser degree on most of the plots. Maximum defoliation was maintained for a year or more on only a few plots.

Only the two higher rates of bromacil and isocil provided more than 70 percent defoliation at the end of the 2-yr. period. The next best treatment was 2,4,5-T:2,4-D but the percentage of defoliation at the end of 2 yr. had been reduced to 35 percent.

The response of live oak plants on plots that were retreated in August 1964 was essentially the same as that obtained for the initial treatments (table 7.20). Maximum defoliation was again recorded 6 mo. after treatment, after which recovery occurred to a greater or lesser degree. Two years after retreatment, defoliation of 70 percent or more was recorded only for paraquat:dicamba and paraquat:bromacil.

Test No. 2.--Eleven herbicides were evaluated for their effectiveness in defoliating live oak on October 31, 1963. Some of the plots were retreated October 29, 1964.

Paraquat and some combinations containing paraquat were the only treatments providing 50 percent or more defoliation 1 wk. after treatment (table 7.21).

Maximum defoliation was obtained 26 wk. after treatment for all herbicides except bromacil, which reached its peak 52 wk. after treatment. Thereafter, the percentage of defoliation decreased or remained at about the same level, depending on the effectiveness of the herbicide. Two years after treatment, one or more rates of picloram, dicamba, bromacil, and picloram:2,4-D provided more than 70 percent defoliation.

The initial response of plants on plots that were retreated on October 29, 1964, was essentially the same as for the first treatments. A defoliation of 100 percent was recorded for paraquat:bromacil 1 week after treatment, but the plants on those plots had been completely defoliated before retreatment. Maximum defoliation from these retreatments was recorded 4 wk. after treatment on all plots except those treated with dicamba. Refoliation had occurred at the end of the 2-yr. period to the extent that only the plots treated with

TABLE 7.21.--The percentage defoliation of live oak resulting from treatmenta with 11 herbicides applied October 31, 1963, and retreatments of the same plots on October 29, 1964. All treatments were applied in a volume of 10 gal. per acre with a truck-mounted contourmatic boom sprayer

Herbicide	Rate	Defoliation, weeks after treatment				
		1	4	26	52	104
Oct. 31, 1963:	Lb. per acre	- - - -Percent - - - - -				
Paraquat	1	40	50	90	25	10
	4	60	70	95	25	--
	8	70	80	100	55	20
2,4,5-T	1	0	20	40	0	--
	4	20	30	83	40	--
	8	20	60	93	30	10
Picloram	1	10	40	80	43	--
	4	0	60	95	95	88
	8	0	70	100	100	98
Dicamba	1	10	20	35	20	8
	4	0	40	80	48	--
	8	20	70	99	93	75
Bromacil	2.5	10	20	10	40	10
	5	10	50	30	95	90
	10	0	30	53	100	98
Paraquat:dicamba(1:4)	5	30	50	93	35	20
(1:2)	6	50	60	97	73	25
(1:1)	8	40	70	99	60	25
Paraquat:bromacil (4:5)	9	60	80	98	100	--
2,4,5-T:paraquat(1:1)	8	40	80	93	20	8
2,4,5-T:picloram(4:1)	1	0	20	55	6	3
2,4,5-T:DEF(1:1)	8	10	40	73	25	8
(1:2)	12	20	50	25	15	10
Picloram:2,4-D(1:4)	4	20	60	90	83	90
	8	20	80	100	78	55
Untreated check	0	0	0	0	0	0
Retreated Oct. 29, 1964:						
Paraquat	4	70	90	88	35	15
2,4,5-T	1	10	55	10	10	5
	4	65	80	60	30	13
Picloram	1	55	83	70	35	13
Dicamba	4	50	65	73	35	18
Paraquat:bromacil (4:5)	4.5	100	100	100	100	100
Untreated check	0	5	0	0	0	5

paraquat:bromacil had an acceptable level of defoliation.

Test No. 3.--Eight herbicides were evaluated for their effectiveness in defoliating live oak on April 14, 1964. This test was intended to extend the range of seasonal applications with herbicides that appeared promising from previous experiments.

Most of the herbicides provided acceptable defoliation 1 week after treatment (table 7.22). Paraquat:dicamba and the two lower rates of 2,4,5-T were obvious exceptions. Maximum defoliation was recorded 4 wk. after treatment for all herbicides except the lowest rate of 2,4,5-T. Thereafter, refoliation occurred to a greater or lesser degree depending on the effectiveness of the herbicides. At the end of the 2-yr. period the highest percentage of defoliation was obtained on plots treated with 8 pounds per acre of picloram, but no treatment caused 70 percent defoliation or greater.

The percentage of defoliation 1 wk. after treatment was generally greater in this test than for those reported previously, but defoliation after 2 yr. was lower. April does not appear to be a good season of treatment for long term defoliation of live oak.

Test No. 4.--Four of the most promising herbicides were evaluated on May 12, 1964. All of the plots were retreated with identical rates on June 17, 1965. Data for 2 yr. posttreatment are not given because all of the plots were retreated.

TABLE 7.22.--The percentage of defoliation of live oak resulting from treatmenta with eight herbicidea applied April 14, 1964. All treatmenta were applied in a volume of 10 gal. per acre with a truck-mounted, contourmatic boom sprayer

Herbicide	Rate	Defoliation, weeks after treatment				
		1	4	26	52	104
	Lb. per acre	- - - - Percent - - - -				
Paraquat	4	53	68	10	15	3
	8	75	85	35	20	3
Picloram	2	45	75	25	30	8
	4	68	100	83	60	50
	8	70	100	94	93	60
2,4,5-T	4	35	63	65	40	10
	8	38	98	55	55	8
	12	63	100	65	40	15
Paraquat:dicamba (1:1)	8	35	83	45	25	5
Paraquat:bromacil (4:5)	9	85	100	70	45	43
2,4,5-T:paraquat (1:1)	8	80	97	65	40	28
2,4,5-T:2,4-D (1:1)	8	70	99	68	40	13
Picloram:paraquat (1:1)	8	85	100	55	55	18
Untreated check	0	5	41	0	0	0

None of the herbicides provided an acceptable level of defoliation within 1 wk. after treatment (table 7.23). The highest defoliation recorded (45 percent) was obtained with 4 lb. per acre of paraquat. Maximum defoliation was obtained 4 wk. after treatment with paraquat and 26 wk. after treatment with all other herbicides. At the end of a year only picloram provided a level of defoliation greater than 70 percent.

The initial defoliation resulting from retreatments was somewhat greater than that from the first treatments, but that occurred only because some of the plants were partly defoliated at the time of retreatment. Maximum defoliation was again recorded 1 mo. after treatment for paraquat and 26 wk. after treatment for all other herbicides. One year after retreatment, both rates of picloram and the 4 lb. rates of 2,4,5-T and paraquat had provided defoliation greater than 70 percent. It is interesting to note that two, 4-lb. treatments with 2,4,5-T were no more effective than a single 4-lb. treatment with picloram. Actually, the level of defoliation on plots initially treated with 4 lb. of picloram was so high that there was little, if any, effect from the second treatment.

Test No. 5.--Ten herbicides, effective in previous treatments, were evaluated for their effectiveness in defoliating live oak on July 13, 1964.

Paraquat and paraquat:dicamba provided a defoliation of 78 percent 1 wk. after treatment (table 7.24). Defoliation resulting from several other treatments also surpassed the minimum standard of 50 percent. Maximum defoliation was recorded 4 wk. after treatment for paraquat:picloram and 26 weeks after treatment for all other herbicides.

Refoliation was high on all plots. Two years after treatment, only bromacil maintained defoliation at more than 70 percent. The effective rate of bromacil cannot be as low as 5 lb. per acre, however. It may be noted that whereas 10 lb. of bromacil caused a defoliation of 100 percent, 5 lb. of bromacil combined with 4 lb. of paraquat produced a defoliation of only 55 percent 2 years after treatment. There was no indication in this test that the addition of paraquat to picloram, 2,4,5-T, dicamba, or bromacil increased the effectiveness of those herbicides.

Test No. 6.--We treated live oak again on October 29, 1964 to provide additional information on five herbicides that had shown

TABLE 7.23.--The percentage of defoliation of live oak resulting from treatments with four herbicides applied May 12, 1964, and retreatments of the same plots on June 17, 1965. All treatments were applied in a volume of 10 gal. per acre with a truck-mounted, contourmatic boom sprayer

Herbicide	Rate	Defoliation, weeks after treatment			
		1	4	26	52
May 12, 1964:	Lb. per acre	- - - Percent - - -			
Paraquat	1	25	55	15	20
	4	45	60	45	45
Picloram	1	5	75	83	73
	4	11	88	93	93
2,4,5-T	1	9	58	45	30
	4	13	60	63	60
Dicamba	1	11	23	30	15
	4	3	20	50	45
Untreated check	0	0	5	0	5
Retreated June 17, 1965:					
Paraquat	1	40	83	73	55
	4	60	90	78	75
Picloram	1	68	85	85	83
	4	93	88	90	85
2,4,5-T	1	10	75	78	55
	4	45	85	88	83
Dicamba	1	18	65	70	55
	4	13	60	73	65
Untreated check	0	0	0	0	0

TABLE 7.24.--The percentage of defoliation of live oak resulting from treatments with 10 herbicides applied July 13, 1964. All treatments were applied in a volume of 10 gal. per acre with a truck-mounted, contourmatic boom sprayer

Herbicide	Rate	Defoliation, weeks after treatment				
		1	4	26	52	104
	Lb. per acre	- - - - - Percent - - - -				
Paraquat	8	78	80	90	60	25
Picloram	8	55	98	99	85	63
2,4,5-T	8	53	93	98	75	30
2,4-D	8	60	73	98	88	45
Dicamba	8	25	90	99	53	20
Bromacil	10	8	94	100	100	100
Paraquat:picloram (1:1)	8	53	90	78	58	15
Paraquat:2,4,5-T (1:1)	8	38	78	93	73	15
Paraquat:dicamba (1:1)	8	78	93	97	78	65
Paraquat:bromacil (4:5)	9	48	98	97	85	55
Untreated check	0	0	0	0	0	0

promise for long term defoliation of live oak. Paraquat was not used in this test.

None of the herbicides proviced an appreciable defoliation 1 wk. after treatment (table 7.25). Maximum defoliation was usually recorded 26 wk after treatment, although the higher rate of 2,4,5-T:bromacil produced maximum defoliation 4 wk. after treatment. At the end of the 2-yr. period, the higher rate of picloram and both rates of bromacil provided a high percentage of defoliation. It is interesting to note that the percentage of defoliation obtained with 2 lb. of picloram was somewhat higher when 0.5 percent DMSO was added to the spray solution. DMSO is known to enhance the absorption and translocation of many chemicals.

Test No. 7.--Treatments for the last test on the defoliation of live oak were applied on June 17, 1965. Twelve herbicides that had shown promise in earlier tests were evaluated.

Only four herbicides provided an acceptable level of defoliation within 1 wk. after treatment (table 7.26). This is somewhat surprising because high rates of paraquat and herbicidal combinations including paraquat were used. The highest percentage of defoliation 1 wk. after treatment was obtained on plots treated with picloram:2,4,5-T.

Maximum defoliation occurred either 4 or 26 wk. after treatment. Some recovery occurred thereafter, but many of the plots had an acceptable level of defoliation 1 yr. after treatment.

DMSO was again added to picloram in this experiment. The percentage of defoliation was significantly greater on plots where DMSO was used. Actually, 2 lb. of picloram, to which 0.5 percent DMSO had been added, was just as effective as 4 lb. of picloram without the DMSO.

Discussion of treatments on live oak.--Paraquat was usually the best herbicide for rapid defoliation of live oak. The rates that were used were probably too low to obtain consistently good short term defoliation. Paraquat was used in seven tests at a rate of 4 lb. per acre. In only one of those tests did defoliation 1 wk. after treatment reach the 70-percent level. In three of five tests at a rate of 8 lb. per acre, the percentage of defoliation 1 wk. after treatment equalled or exceeded 70 percent. If paraquat were used

TABLE 7.25.--The percentage defoliation of live oak resulting from treatments with five herbicides applied October 29, 1964. All treatments were applied in a volume of 10 gal. per acre with a truck-mounted, contourmatic boom sprayer

Herbicide	Rate	Defoliation, weeks after treatment				
		1	4	26	52	104
	Lb. per acre	- - - - Percent - - - -				
Picloram + 0.5 percent DMSO	2	3	97	98	88	60
Picloram	2	3	85	94	83	50
	8	20	99	100	100	100
2,4,5-T	2	0	25	35	25	0
	8	3	94	90	78	35
Dicamba	2	3	60	85	45	20
	8	0	97	99	75	40
Bromacil	5	0	35	15	95	95
	10	0	40	38	100	100
Untreated check	0	0	0	0	0	0

TABLE 7.26.--The percentage defoliation of live oak resulting from treatments with 12 herbicides applied June 17, 1965. All treatments were applied in a volume of 10 gal. per acre with a truck-mounted, contourmatic boom sprayer

Herbicide	Rate	Defoliation, weeks after treatment			
		1	4	26	52
	Lb. per acre	- - - Percent - - -			
Paraquat	4	55	90	90	63
	8	45	88	88	60
Picloram + 0.5 percent DMSO	2	30	95	97	93
Picloram	2	30	93	83	50
	4	45	100	99	93
	8	45	100	100	100
Dicamba	4	55	99	94	70
	8	15	90	80	45
2,4,5-T	4	23	97	93	73
	8	30	90	85	55
Bromacil	4	20	79	89	58
	8	20	68	100	100
Paraquat:picloram (1:1)	8	40	99	97	95
Paraquat:dicamba (1:1)	8	35	98	95	95
Paraquat:2,4,5-T (1:1)	8	50	99	97	83
Paraquat:bromacil (1:1)	8	40	94	93	83
Picloram:bromacil (1:2)	6	40	99	90	85
Picloram:2,4,5-T (1:1)	8	65	100	100	98
Untreated check	0	0	10	0	0

for the defoliation of live oak, a rate higher than 8 lb. per acre would provide acceptable short term defoliation.

Picloram and bromacil were the best herbicides for long term defoliation of live oak. The choice of either picloram or bromacil for the control of live oak would depend not so much on effectiveness of the herbicides as on other factors, such as, cost of the treatment, suitability for the type of spray equipment available, and the effect on associated vegetation. Picloram would be more effective on associated woody species, whereas bromacil would be more effective for the control of associated grasses.

Picloram was used in four of the tests for the control of live oak. One year after treatment, defoliation was only 60 percent for one of those treatments, but more than 90 percent for the other three treatments. Eight pounds of picloram was used in five tests. A defoliation of 85 percent was recorded in one test, 93 percent in another, and 100 percent in the other three.

Bromacil was used in three tests at a rate of 5 lb. per acre. In each case defoliation was 95 percent 1 yr. after treatment. Bromacil at 10 lb. per acre was evaluated in five tests. In each case, defoliation was 100 percent 1 yr. after treatment. Thus, both picloram and bromacil are effective herbicides for the defoliation and control of live oak. The decision on which of the herbicides to use would depend on the specific objectives of the user.

Additional information was obtained in the course of this study on the effect of paraquat when added to picloram, dicamba, bromacil, and 2,4,5-T. Paraquat did not enhance the effectiveness of picloarm at any time. The effectiveness of bromacil and 2,4,5-T was reduced in one test, but had no effect in another, and was enhanced in the third. The effectiveness of dicamba was enhanced by the addition of paraquat in all of the three tests where the combination was evaluated. These results are far different from those obtained on the three species in the Post Oak Savannah.

Mixed Hardwoods

The mixed hardwoods of the Piney Woods of Texas are a relatively complex association of woody species. The treatments were made in an area where the mature oak-pine had been cut and subsequently invaded by woody species such as sumac, saw greenbriar, sassafras, Allegheny chinquapin, tupelo, American beech, and sweetbay magnolia. Other woody species were also present, but those listed were most common.

Most of the species are deciduous. Growth and development start in the spring period when rising temperatures interrupt winter dormancy. Rainfall at this time of the year is adequate for good plant growth.

The treatments on mixed hardwoods were made at various seasons of the year starting in August 1963 and continuing through August 1965. Applications were made with a contourmatic boom sprayer mounted on a 3/4-ton pickup. Two plots, 22 by 200 ft., were sprayed for each treatment. All of the treatments were applied in a volume of 10 gal. per acre.

Test No. 1.--The first test on defoliation and control of mixed hardwood species in the Piney Woods was applied August 28, 1963. Sixteen herbicides and herbicidal combinations were evaluated.

Diquat, paraquat, and combinations containing paraquat were the only herbicides that provided greater than 50 percent defoliation 1 wk. after treatment (table 7.27). One month after treatment, one or more rates of all herbicides except DEF and fenuron had provided a defoliation of 50 percent or more.

Dicamba was the best of the herbicides evaluated in this test for the long term defoliation of mixed hardwoods. The difference in defoliation between plots treated with 4 and 8 lb. per acre of dicamba was not significant. Poor control, on a long term basis, was obtained with 2,4,5-T and 2,4,5-T:2,4-D was no better. The addition of ammonium thiocyanate to 2,4,5-T increased the effect somewhat. Herbicidal combinations that included paraquat produced variable results. The addition of paraquat reduced the activity of dicamba, but did not affect 2,4,5-T and bromacil.

Test No. 2.--Eight herbicides were evaluated for their effectiveness in defoliating mixed hardwoods on April 22, 1964. Objectives of the study were to determine which herbicides were most effective for rapid defoliation and which were most effective for long term defoliation.

TABLE 7.27.--The percentage of defoliation of mixed brush in the Piney Woods resulting from treatments with 16 herbicides applied August 28, 1963. All treatments were applied in a volume of 10 gal. per acre with a truck-mounted, contourmatic boom sprayer

Herbicide	Rate	Defoliation, weeks after treatment			
		1	4	52	104
	Lb. per acre	- - - Percent - - -			
Dicamba	4	28	64	93	65
	8	26	72	60	60
	12	26	68	90	70
Diquat	2	74	68	10	5
	4	66	68	10	5
	8	66	74	20	15
Paraquat	2	58	60	5	0
	4	62	66	15	15
	8	76	72	15	10
2,3,6-TBA	4	26	34	20	5
	8	28	44	20	15
	12	36	60	30	15
2,4,5-T	4	28	70	65	40
	8	28	76	40	30
	12	28	74	35	20
DEF	2	14	0	0	0
	4	12	36	0	5
	8	8	0	0	5
Isocil	2.5	16	40	5	5
	5	14	60	40	30
Bromacil	2.5	14	52	0	0
	5	32	50	15	5
	10	24	66	55	40
Fenuron	5	10	28	5	5
Dicamba:2,4,5-T (1:1)	8	20	76	60	50
Dicamba:paraquat (1:1)	8	66	70	25	10
Paraquat:2,4,5-T (1:1)	8	68	80	80	95
Paraquat:bromacil (1:1)	8	62	70	10	5
2,4,5-T:2,4-D (1:1)	4	24	66	65	25
	8	22	64	30	20
	12	30	70	45	50
2,4,5-T:ammonium thiocyanate (8:1)	4.5	24	68	70	40
2,4,5-T:DEF (1:1)	8	40	72	30	15
Untreated check	0	8	0	5	0

One week after treatment, acceptable defoliation was obtained with paraquat and combinations containing paraquat (table 7.28). There was rapid recovery, however, on all plots where plants were defoliated rapidly. Paraquat:picloram was the only herbicide that provided rapid defoliation and also good long term defoliation. Two years after treatment,

TABLE 7.28.--The percentage defoliation of mixed brush in the Piney Woods resulting from treatments with eight herbicides applied April 22, 1964. All treatments were applied in a volume of 10 gal. per acre with a truck-mounted, contourmatic boom sprayer

Herbicide	Rate	Defoliation, weeks after treatment				
		1	4	26	52	104
	Lb. per acre	- - - -Percent- - - - -				
Paraquat	4	62	71	20	20	5
	8	61	60	10	10	0
2,4,5-T	4	21	88	85	80	20
	8	17	79	75	82	65
	12	30	84	60	60	40
Picloram	4	26	69	90	92	70
	8	19	82	95	100	92
Dicamba:paraquat (1:1)	8	64	74	40	50	5
Paraquat:2,4,5-T (1:1)	8	67	85	45	15	0
Paraquat:bromacil (1:1)	8	57	60	50	5	5
2,4,5-T:2,4-D (1:1)	12	28	87	75	75	35
Paraquat:picloram (1:1)	8	66	88	95	95	88
Untreated check	0	5	2	0	0	0

the best defoliation occurred on plots treated with picloram and with paraquat:picloram.

The addition of paraquat to spray solutions decreased the long term activity of 2,4,5-T. Two years after treatment, defoliation of plots treated with 4 lb. per acre of 2,4,5-T was 20 percent. When paraquat was added to the same rate of 2,4,5-T, the defoliation at the end of 2 yr. was zero. Paraquat seemed to enhance the activity of picloram, on the other hand. Two years after treatment, plots treated with 4 lb. per acre of picloram had a defoliation of 70 percent as opposed to 88 percent for the paraquat:picloram combination.

Test No. 3.--Ten herbicides were evaluated for their effectiveness in defoliating mixed hardwoods on July 9, 1964. Essentially the same herbicides were used as in the previous experiment, but dicamba and bromacil at rates of 5 and 10 lb. per acre were added to provide a direct comparison with the herbicidal combinations of which dicamba and bromacil were a part.

As was the case in the previous test, acceptable defoliation 1 wk. after treatment was obtained with paraquat and all combinations containing paraquat (table 7.29). Refoliation occurred rapidly on most of the treated

TABLE 7.29.--The percentage defoliation of mixed brush in the Piney Woods resulting from treatments with ten herbicides applied July 9, 1964. All treatments were applied in a volume of 10 gal. per acre with a truck-mounted, contourmatic boom sprayer

Herbicide	Rate	Defoliation, weeks after treatment			
		1	4	52	104
	Lb. per acre	- - - -Percent- - -			
Paraquat	4	59	63	5	0
2,4,5-T	4	38	64	40	20
	8	31	83	70	40
	12	34	78	65	45
Picloram	4	38	67	55	60
	8	24	71	70	75
Dicamba	5	19	51	10	0
Bromacil	10	33	65	65	45
Dicamba:paraquat (1:1)	8	60	67	15	0
Paraquat:2,4,5-T (1:1)	8	64	80	45	15
Paraquat:bromacil (1:1)	8	71	73	15	10
Paraquat:picloram (1:1)	8	69	81	50	15
2,4,5-T:2,4-D (1:1)	12	46	71	60	55
Untreated check	0	7	11	0	0

plots, however. Two yr. after treatment, only the 8 lb. rate of picloram provided an acceptable level of defoliation.

In this test paraquat reduced the activity of picloram and bromacil, but had no effect on dicamba or 2,4,5-T. This is in contrast to the situation in Test No. 2, where paraquat reduced the effectiveness of 2,4,5-T but enhanced the effectiveness of picloram. The reasons for the differences between the two treatment dates are not known.

Test No. 4.--Four herbicides were evaluated on four different treatment dates in 1965. One of the treatments, 2,4,5-T:2,4-D, was the control against which other herbicides were evaluated. Picloram and picloram:paraquat were included in the test because previous work had shown them to be the most effective herbicides for the control of the mixed brush in the Piney Woods of Texas. A combination of three herbicides, 2,4,5-T:picloram:paraquat, was added to this test to determine if the three-way combination would control a broader spectrum of brush species than other herbicides or combinations.

The primary purpose of this test was to evaluate the herbicides on the basis of their effectiveness in providing long term defoliation of mixed brush. Defoliation data taken 1 and 4 wk. after treatment are not given because the results were similar to what had been obtained in earlier tests.

The data indicate clearly that picloram, or any combination including picloram, is more effective for the defoliation and control of mixed brush than is 2,4,5-T:2,4-D (table 7.30). Picloram at 2 lb. per acre was more effective than 2,4,5-T:2,4-D at 8 lb. per acre. The three-way combination appeared to be more effective than any other treatment. Better results were obtained from spring treatments than from summer treatments.

Discussion of treatments on mixed hardwoods.--When the results of all treatments are combined, it is clear that the best herbicide in terms of long term defoliation is picloram. Combinations containing picloram were also effective. Dicamba gave reasonably good defoliation in one test but was far below the performance of picloram in all other tests.

Paraquat and diquat were the best herbicides tested for rapid defoliation of mixed brush in the Piney Woods. There was very little difference between the performance levels of the two herbicides and since the reaction of the plant species to them was so similar, only

TABLE 7.30.--The percentage of defoliation of mixed brush 1 yr. after treatment resulting from treatments on four dates in 1965. All treatments were applied in a volume of 10 gal. per acre with a truck-mounted, contourmatic boom sprayer

Herbicide	Rate	Defoliation 1 yr. after treatment in 1965 on--			
		Apr. 20	May 26	Aug. 2	Aug. 30
	Lb. per acre	- - - -Percent- - - -			
Picloram	2	40	55	60	60
	4	80	90	65	65
Picloram:paraquat (1:2)	6	--	75	55	65
(1:1)	8	92	50	65	75
2,4,5-T:2,4-D (1:1)	8	25	35	65	30
2,4,5-T:picloram:paraquat					
(1:1:1)	6	--	92	90	75
(1:1:2)	8	--	60	80	50

paraquat was used in most of the tests. Herbicidal combinations that included paraquat also usually gave more rapid defoliation of the mixed brush than did the companion herbicide used alone.

No constant effect was noted for the addition of paraquat to other herbicides. The activity of dicamba, 2,4,5-T, and bromacil was reduced or unaffected by paraquat. When paraquat was added to picloram, the activity of picloram was enhanced in three cases, not affected in one case, and reduced in two cases. There have also been cases with other plant species when the addition of paraquat reduced the effectiveness of picloram, cases in which the effect of picloram was not affected, and still other cases in which the effect of picloram was enhanced. The reaction does not appear to be related to a plant species nor does it appear to be related to the season of treatment. Before the combination of picloram with paraquat can be generally recommended, additional work needs to be done. The addition of paraquat to another herbicide is desirable because both rapid and long term defoliation are possible. Experience has shown, however, that the reaction is variable and cannot be predicted.

Mixed brush of the Piney Woods is most susceptible in the spring. That period ties in well with phenologic development. The most susceptible period occurs at the expected time as discussed in chapter 9.

Treatments in Puerto

Guava

Guava has a pan-tropical distribution. It is resistant to most herbicides so it is a good test species in that a herbicide that will control guava will probably also control many other tropical species. Most of the applications on guava were made with a portable, compressed-air sprayer. A high volume of spray solution per plant was used for these treatments. Spraying was continued until most of the leaves were wet. The herbicidal concentration for these tests was expressed in terms of acid equivalent per 100 gal. of spray solution. Water was used as the diluent in all the tests.

Applications were also made with a telescoping pole sprayer on four treatment dates. The design and operation of the telescoping pole sprayer is described in chapter 11. Herbicidal concentration for the treatments made with the telescoping pole sprayer are expressed in terms of pounds per acre.

A randomized block experimental design was used for all treatments made with the portable, compressed-air sprayer. Twenty plants were sprayed for each treatment. For the purpose of analysis, each plant was considered a replication. Unreplicated plots were used for the telescoping pole treatments, and five or six plants were marked on each of the plots from which data were obtained.

Test No. 1.--Thirteen herbicides were evaluated for their effectiveness in defoliating guava in October 1963. The 9-lb. rate of diquat and the 18-lb. rate of butynediol were the only treatments that resulted in more than 50-percent defoliation 1 wk. after treatment (table 7.31). Refoliation occurred rapidly and, 1 yr. after treatment, the percentage of defoliation was extremely low. Of the herbicides evaluated in this test, diquat, paraquat, folex, and butynediol are rapid defoliants. Folex was the least effective of the four and none of them provided long term defoliation. The percentage of defoliation for all of these herbicides 1 yr. after treatment was essentially zero.

Defoliation exceeding 70 percent 1 yr. after treatment was obtained only with 18 lb. of 2,4-D and 2 lb. of 2,4,5-T. Plots treated with picloram and dicamba refoliated rapidly between the 26- and 52-week observations.

Test No. 2.--Eleven herbicides were evaluated from treatments made in December 1963. Most of the herbicides used in the first test were again used in this test to get a better idea of their performance in a different season of the year. Amitrole-T and diuron were dropped from the test program on guava because they were obviously ineffective. Isocil was also deleted because its activity was very similar to bromacil and thus, there was no

TABLE 7.31.--The percentage defoliation of guava reaulting from treatments with 13 herbicides applied in October 1963. Wetting spraya were applied with a portable, compresaed-air sprayer

Herbicide	Rate	Defoliation, weeka after treatment			
		1	4	26	52
	Lb. per 100 gal.	- - - Percent[1] - - -			
2,4-D:2,4,5-T (1:1)	2	0	28/19	22	7
	6	0	51/25	33	13
	18	0	42/26	35	15
2,4-D	2	0	53/36	28	1
	6	0	76/32	67	24
	18	0	77/35	10	83
2,4,5-T	2	0	77/35	10	83
	6	0	66/41	31	11
	18	0	84/56	59	4
Picloram	1	0	16/14	10	0
	3	0	45/38	51	35
	9	0	70/46	85	65
Dicamba	1	0	10/10	13	4
	3	0	27/20	49	1
	9	0	58/30	94	63
Amitrole-T	2	0	10/10	1	0
	6	0	10/10	0	0
	18	0	10/10	0	0
Bromacil	2	0	1/1	1	0
	6	0	21/16	10	4
	[2] 6	2	43/41	6	0
	8	0	14/13	70	2
Isocil	2	0	1/1	10	2
	6	0	13/13	0	0
	[2] 6	11	18/18	2	0
	18	0	30/30	10	0
Diuron	2	0	3/3	6	1
	6	0	9/9	4	0
	[2] 6	6	26/26	10	5
	18	0	19/18	8	0
Diquat	1	0	13/13	6	0
	3	13	37/37	0	0
	[2] 3	10	12/12	1	0
	9	82	85/81	8	7
Paraquat	1	0	11/11	8	0
	3	13	43/43	4	0
	[2] 3	37	46/46	2	0
	9	20	58/58	2	0
Folex	2	0	0	0	0
	6	0	4/4	18	1
	18	0	5/5	0	0
Butynediol	2	0	0	9	0
	6	0	10/10	2	0
	18	64	70/70	5	0

[1] Where double figurea are given, that left of the diagonal line repreaenta desiccstion plus defolistion; that to the right represents defoliation. Single figures represent defoliation only.

[2] Surfactant X-77 added at 1 percent.

reason for continuing with two herbicides having similar chemical structure.

One of the objectives of this test was to determine influence of a surfactant on herbicidal activity. The surfactant used for that purpose was X-77.

Diquat, to which X-77 was added, was the only herbicide evaluated in the second test that gave satisfactory defoliation within 1 wk. after treatment (table 7.32). The surfactant definitely increased the activity obtained from dicamba, diquat, and paraquat, but did not have an appreciable effect on other herbicides with which it was used.

One year after treatment, two or more rates of picloram and dicamba were the only herbicides that provided acceptable defoliation. The activity obtained from picloram was much greater in this test than in the first test. The cause of the increased activity is no doubt due to the addition of an antifoam agent to the picloram solution. The first samples of picloram did not contain an antifoam agent in the formulated product and consequently, a great deal of foaming was encountered. Subsequent samples of picloram did contain an antifoam agent so that problem was resolved.

Even though the surfactant did increase the activity of diquat and paraquat, it did not serve to extend the period of defoliation that is normally obtained with those herbicides. One year after treatment, plants that had been treated with diquat and paraquat had recovered almost completely.

It is of interest to note that 6 lb. of dicamba, to which X-77 had been added, was just as effective as 18 lb. of dicamba to which no surfactant had been added. The experience gained in this test, and previous experiences as well, suggests that the addition of a surfactant to a herbicidal spray solution will often enhance the effectiveness of herbicides. There are some cases in which a surfactant reduces the effectiveness of a herbicide (6, 7). Enough is known about the surfactant-herbicide interaction, however, to safely say that if the surfactant and the herbicide are compatible,

TABLE 7.32.--The percentage defoliation of gusva resulting from treatments with 11 herbicides applied in December 1963. Wetting sprays were applied with s portsble, compressed-air sprayer

Herbicide	Rate	Defoliation, weeks after trestment			
		1	4	26	52
	Lb. per 100 gsl.	- - - - -	Percent[1]	- - -	
2,4-D:2,4,5-T (1:1)	2	0	27/15	15	3
	6	0	46/24	35	12
	18	0	66/28	53	24
2,4-D	2	0	34/18	22	7
	6	0	47/24	31	17
	18	0	67/23	62	41
2,4,5-T	2	0	27/16	10	2
	6	0	60/43	23	7
	18	0	66/35	65	44
Picloram	2	0	67/33	85	70
	6	0	77/33	95	94
	18	16/1	93/29	100	100
Dicambs	2	0	28/22	16	11
	[2] 2	0	27/17	50	33
	6	0	61/38	80	63
	[2] 6	0	64/34	88	87
	18	0	80/40	90	81
	[2] 18	0	86/34	100	97
Bromacil	18	0	22/22	11	3
	[2] 18	0	24/24	16	3
Diquat	6	26/12	38/38	0	0
	[2] 6	55/16	70/63	15	2
	18	40/14	64/57	10	2
Parsqust	6	0	13/13	0	0
	[2] 6	27/7	45/42	11	2
	18	18/7	22/21	0	0
Folex	18	0	43/43	2	0
	[2] 18	0	35/35	0	0
Butynediol	18	0	37/37	0	0
	[2] 18	30/12	47/47	3	0
DEF	18	0	31/31	0	0
	[2] 18	0	28/28	2	0

[1] Where double figures are given, that left of the disgonsl line represents desiccation plus defoliation; that to the right represents defolistion. Single figures represent defoliation only.
[2] Surfactsnt X-77 sdded st 1 percent.

the herbicidal effect will be enhanced more often than reduced.

Test No. 3.--Five herbicides were evaluated from treatments made in March 1964. Picloram and dicamba were included in the tests because they were the most promising of the long term defoliants. Diquat and paraquat were included in the test because they were the most promising of the rapid defoliants. All of the herbicides were compared with 2,4-D:2,4,5-T, which was used as the control. An additional objective of the study was to obtain more information on the effects of a surfactant added to picloram, diquat, and paraquat.

Both diquat and paraquat provided satisfactory levels of defoliation 1 wk. after treatment (table 7.33). The enhanced defoliation obtained with X-77 was not great, but it was consistent. As was the case in the previous test, the addition of X-77 to diquat and paraquat did not increase the period of time during which defoliation of guava was maintained. Almost complete recovery had occurred within 6 mo. after treatment.

The addition to picloram of an antifoam agent, X-77, separately and both materials together, produced some interesting results. One week

TABLE 7.33.--The percentage defoliation of gusva resulting from treatments with five herbicides applied in March 1964. Wetting sprays were applied with a portable, compressed-air sprayer

Herbicide	Rate	Defoliation, weeks after treatment			
		1	4	26	52
	Lb. per 100 gal.	- - - - -	Percent[1]	- - - - -	
2,4-D:2,4,5-T (1:1)	2	0	90/73	11	4
	6	0	94/43	29	10
	18	0	98/42	47	23
Picloram	[2] 2	28/12	87/80	37	25
	[3] 2	0	94/58	67	53
	[4] 2	47/20	89/73	46	20
	[2] 6	51/24	93/63	85	76
	[3] 6	0	96/31	94	90
	[4] 6	52/17	96/48	87	77
	[2] 18	63/14	97/36	93	90
	[3] 18	0	88/31	100	100
	[4] 18	63/13	97/47	96	96
Dicamba	2	0	76/59	33	6
	6	0	89/51	69	50
	18	0	97/73	47	41
Diquat	2	67/24	92/92	0	0
	[3] 2	74/29	96/89	3	0
	6	82/23	93/86	4	0
	[3] 6	85/16	96/91	7	3
	18	89/25	97/95	9	4
	[3] 18	94/22	98/89	13	4
Paraqust	2	49/43	75/75	0	2
	[3] 2	61/61	82/82	1	0
	6	89/88	95/95	1	0
	[3] 6	88/84	96/96	2	0
	18	94/81	98/98	3	0
	[3] 18	95/72	96/93	1	0

[1] Where double figures sre given, that left of the diagonal line represents desiccation plus defoliation; that to the right represents defoliation. Single figures represent defoliation only.
[2] 1 percent antifoam agent added.
[3] 1 percent X-77 added.
[4] 1 percent each of antifoam and X-77 added.

after treatment, there was no defoliation recorded for plants treated with picloram to which X-77 had been added. Some defoliation was recorded on all plots treated with picloram to which an antifoam agent had been added, however. When both antifoam and X-77 were added to picloram, the results 1 wk. after treatment were essentially the same as on plots where only the antifoam had been added. One year after treatment, the results were quite different. At this time, the best results were obtained on plots treated with picloram to which X-77 had been added. Once again, the results obtained with the addition of an antifoam or both an antifoam and X-77 were about the same, but the levels of defoliation were considerably lower than on plots where only X-77 was used. The data emphasize the importance of adding surfactant to a herbicidal solution, but suggest caution on the kinds of surfactants that are used. These data are in agreement with other work that has been done regarding the influence of surfactants in herbicidal solutions.

Diquat and paraquat were the most effective herbicides for rapid defoliation. Picloram was the best herbicide for long term defoliation. Dicamba and 2,4-D:2,4,5-T were less effective than picloram for both initial and long term defoliation.

Test No. 4.--Eleven herbicides were evaluated from applications made in June 1964. The principal purpose of this test was to evaluate combinations of herbicides and compare their effectiveness with single herbicides. Previous work had shown that the addition of the surfactant X-77 did not reduce herbicidal effectiveness and in most cases enhanced it. Consequently, in this test and in all future tests, the addition of 1 percent X-77 became standard practice.

None of the herbicides evaluated in this test provided rapid defoliation (table 7.34). One month after treatment, bromacil:paraquat was the only herbicide that provided an acceptable level of defoliation. The same relationship carried through until the end of the study period 1 yr. after treatment. At that time bromacil:paraquat was still the most effective herbicide, but the level of defoliation was far below an acceptable standard.

Bromacil was the only herbicide whose activity was enhanced by the addition of paraquat. The levels of defoliation 1 yr. after treatment indicate that picloram, dicamba, and 2,4-D:2,4,5-T were not influenced by the addition of paraquat. Rapidity of defoliation was quite another matter. Ordinarily, considerable defoliation is obtained 1 wk. after treatment from an application of 4 lb. of paraquat. In this test, however, no defoliation was recorded 1 wk. after treatment for those treatments where 2,4-D:2,4,5-T, picloram, dicamba, and bromacil were combined with paraquat. Thus, one may conclude that the four herbicides were antagonistic to paraquat. Paraquat did not reduce the effectiveness of 2,4-D:2,4,5-T, picloram, or dicamba and enhanced the activity of bromacil.

Reduced activity of paraquat was also noticeable for three-way combinations. Long term defoliation of guava by the three-way combinations was certainly not enhanced. There is some suggestion that the herbicides were antagonistic to each other.

TABLE 7.34.--The percentage defoliation of guava resulting from treatments with 11 herbicides applied in June 1964. Wetting sprays were applied with a portable, compressed-air sprayer

Herbicide	Rate	Defoliation, weeks after treatment			
		1	4	26	52
	Lb. per 100 gal.	- - - Percent[1] - - -			
2,4-D:2,4,5-T (1:1)	6	0	53/33	61	35
Picloram	2	0	19/19	19	10
Dicamba	6	0	23/22	30	25
Bromacil	18	0	44/43	25	15
2,4-D:2,4,5-T:paraquat (3:3:4)	10	0	58/34	50	32
Picloram:paraquat (1:2)	6	0	30/29	25	15
Dicamba:paraquat (3:2)	10	0	27/27	40	21
Bromacil:paraquat (9:2)	22	0	84/84	40	40
Picloram:dicamba:paraquat (1:1:1)	6 12	0 0	25/25 24/18	41 47	29 39
Picloram:bromacil:paraquat (1:1:1)	6	0	25/24	15	5
Dicamba:bromacil:paraquat (1:1:1)	6	0	17/16	3	2

[1] Where double figures are given, that left of the diagonal line represents desiccation plus defoliation; that to the right represents defoliation. Single figures represent defoliation only.

Test No. 5.--The last three treatment dates for which a portable, compressed-air sprayer was used to evaluate herbicides in defoliating guava are combined for ease of discussion. The treatment dates were December 1964, and May and August 1965.

There are several interesting aspects of these studies (table 7.35). The treatments made in December 1965 show that there was no difference between 4, 5, and 6 lb. of picloram. Previous tests had shown that 2 lb. of picloram was inadequate for effective control, whereas 6 lb. always gave effective control. This test showed that 4 lb. of picloram was just as effective as was 6 lb. The coded material, GS-14260 was not effective and was not used in any subsequent tests.

TABLE 7.35.--The percentage defoliation of guava rcaulting from treatmenta in December 1964 and in May and Auguat 1965. A wetting apray was applied with a portable, compressed-air sprayer

Treatment date and herbicide	Rate	Defoliation, weeks after treatment			
		1	4	26	52
	Lb. per 100 gal.	- - - Percent[1] - - -			
December 1964:					
Picloram	4	0	52/25	92	89
	5	0	46/27	86	87
	6	0	64/31	95	95
GS-14260	2	0	5	0	0
	6	0	8	1	20
	18	0	15	3	45
May 1965:					
Picloram	6	0	36/20	75	95
2,4-D:2,4,5-T (1:1)	6	0	63/33	72	63
Banvel K	6	0	38/16	62	36
	18	0	59/24	69	--
Pyriclor	2	0	23/23	10	3
	6	0	79/79	38	14
	18	0	95/95	41	37
August 1965:					
2,4-D:2,4,5-T (1:1)	6	0	43/12	43	29
Pyriclor	18	21/9	33/30	15	6
Paraquat	18	27/11	32/26	3	1
Pyriclor:picloram (3:1)	24	43/11	59/42	46	36
Pyriclor:paraquat (1:1)	12	0	18/18	5	5
Pyriclor:paraquat: picloram (1:1:1)	18	0	41/33	26	13

[1] Where double figures are given, that left of the diagonal line representa desiccation plus defoliation; that to the right represents defoliation. Single figures represent defoliation only.

The applications made in May 1965 show that picloram was again the most effective herbicide for long term defoliation of guava. Banvel K was less effective than the equivalent rates of 2,4-D:2,4,5-T. Pyriclor was expected to provide a rapid defoliation, but did not do so in this test. A rate of 6 or 18 lb. gave effective defoliation 1 mo. after treatment, but considerable recovery took place and the defoliation 1 yr. after treatment was less than satisfactory.

Additional combinations were used in treatments made in August 1965. Pyriclor and paraquat were about equally effective in this test, but the level of defoliation achieved 1 wk. and 4 wk. after treatment was not satisfactory. Pyriclor and paraquat were apparently mutually antagonistic when combined. They did not provide any defoliation 1 wk. after treatment, and the highest effect obtained 4 wk. after treatment was still very low. The same was true for the three-way combination of pyriclor:paraquat:picloram.

This test provides additional information suggesting that the use of combinations is fraught with difficulties and the reaction of the plants cannot be predicted.

Test No. 6.--Treatments were made on guava with a telescoping-pole sprayer on three treatment dates in 1966. The purpose of these tests was to compare orange with other herbicides that had shown promise for the control of guava and other tropical woody species. All of the materials were applied in a volume of 10 gal. per acre. Water was used as the diluent for all herbicides except orange and M-2993 for which acetone was used because the materials would not emulsify in water.

The first treatment applied in May 1966 showed that the most rapid defoliation was obtained with orange, but the highest ultimate defoliation was obtained with 30 lb. per acre of M-2993 (table 7.36). It is of particular interest to note that 24 lb. per acre of orange was no more effective than a mixture of orange:picloram which contained 16 lb. of orange and 2 lb. of picloram. In addition, 8 lb. of orange and 4 lb. of picloram, for a total of 12 lb. per acre, was just as effective as 24 lb. of orange. The test suggests strongly that the addition of picloram to the phenoxy herbicides will result in greater herbicidal effectiveness. The latest data available for this test were

TABLE 7.36.--The percentage defoliation of guava resulting from treatments in May, August, and October 1966. All treatments were applied in a volume of 10 gal. per acre with a telescoping-pole sprayer

Treatment date and herbicide	Rate	Defoliation, weeks after treatment			
		1	4	13	26
	Lb. per 100 gal.	- - - - Percent[1] - - - -			
May 1966:					
Picloram	6	1/0	15/15	53	53
	12	1/0	17/10	35	55
2,4-D:2,4,5-T (1:1)	24	32/2	90/38	95	53
Paraquat	12	12/0	32/21	22	16
M-2993	15	17/0	72/34	80	54
	30	31/6	98/36	100	92
Orange	24	55/5	82/38	92	70
Paraquat:picloram (1:1)	12	6/0	27/25	77	50
Orange:picloram (2:1)	12	30/0	66/20	95	73
(8:1)	18	19/0	92/26	95	77
August 1966:					
Picloram	6	3/0	83/61	93	100
	12	5/0	97/77	100	100
Orange	24	50/4	95/84	99	99
M-2993	15	8/0	82/57	92	89
	30	26/14	89/66	98	96
Paraquat:picloram (1:1)	12	58/10	100/73	100	100
Orange:picloram (2:1)	12	22/2	70/51	77	79
October 1966:					
Picloram	6	17/6	93/54	99	([2])
Orange	24	60/16	92/36	96	([2])
M-2993	7.5	7/0	87/46	95	([2])
	15	17/6	89/41	97	([2])
M-3140	7.5	11/2	95/56	97	([2])
	10	8/0	94/29	95	([2])
	15	18/8	96/38	99	([2])

[1] Where double figures are given, that left of the diagonal line represents desiccation plus defoliation; that to the right represents defoliation. Single figures represent defoliation only.

[2] No data.

taken 26 wk. after treatment. The plots will be rated again 1 yr. after treatment to determine whether the long term effects correspond with what was obtained at the latest reading now available.

The second test with the telescoping-pole sprayer on guava was applied in August 1966. In this test, orange and paraquat:picloram provided about the same level of defoliation 1 wk. after treatment but the effects were not satisfactory (table 7.36). The latest available ratings were taken 13 wk. after treament. At that time, the herbicidal effect from picloram, orange, M-2993, and paraquat:picloram was essentially the same. The level of defoliation was lower, however, for the combination of orange:picloram.

The last treatment using the telescoping-pole sprayer on guava was applied in October 1966. Orange provided the highest percentage of defoliation 1 wk. after treatment (table 7.36). Thirteen weeks after treatment, there was no significant difference between the four herbicides. It is of interest to note, however, that a higher herbicidal rate was used for orange than for the other three herbicides. Even so, the levels of defoliation 13 wk. after treatment were essentially the same.

Discussion of treatments on guava.--Diquat and paraquat were the most effective herbicides for rapid defoliation of guava. Other materials manufactured and sold as defoliants (DEF, folex, butynediol) were much less effective. The activity of diquat and paraquat was enhanced by the addition of X-77. The increased activity was often small, but always consistent. The surfactant was particularly beneficial when added to low rates of diquat and paraquat.

Picloram was the most effective herbicide for long term defoliation of guava. Dicamba and 2,4-D were effective in a few tests, but they were not consistently effective as was picloram. Herbicidal combinations were less effective than picloram used alone.

The best season of treatment varied depending on whether rapid or long term defoliation was the desired objective (11 and chapter 9). Treatments made during the February-April period resulted in a high initial defoliation, but plants recovered rapidly between 1 and 6 mo. after treatment. There was additional recovery between the 6-mo. and 1-yr. observations so that the ultimate effect was negligible. Treatments applied during the May-September period caused the lowest initial defoliation, but gave the highest ultimate defoliation and kill. The effects of the October-January treatments were intermediate between the other two.

High initial defoliation of guava is associated with the dry season when flowering and fruit set occur. High long term defoliation is associated with a period of high rainfall and maximum foliar development.

The research on guava emphasized the importance of surfactants for enhancing herbicidal activity. Surfactants were particularly effective when used with water-soluble herbicides such as diquat, paraquat, and dicamba. However, the surfactant to be used must be selected with care. Research has been reported in which a particular surfactant inhibited the activity of a herbicide. For general use, X-77 is known to enhance the activity of many herbicides and is likely to reduce the activity of none.

Sufficient time has not yet elapsed to determine the effects of herbicides that were compared with orange. Short term observations suggest that orange is a rapid defoliant and its activity will not be surpassed by many herbicides. Six-month data from treatments made in May 1966 suggest that herbicidal solutions containing picloram will provide better long term effects than will orange.

Mango

Treatments were applied on mango with a telescoping-pole sprayer in November 1965 and May 1966 in a volume of 10 gal. per acre. Water was used as the diluent in most cases. Acetone was used as a diluent for orange and M-2993. Mango is another cosmopolitan species and little was known of its reaction to herbicides.

No herbicide gave a satisfactory defoliation of mango within 1 wk. after treatment (table 7.37). One year after treatment, 100 percent defoliation was obtained with both 6- and 12-lb. per acre rates of picloram, which was unquestionably the most effective herbicide. Paraquat:picloram resulted in 78 percent defoliation 1 yr. after treatment, but the 6 lb. of the picloram used in the combination with paraquat were not as effective as 6 lb. of picloram used alone.

The second treatment on mango was applied in May 1966. Once again no herbicide provided satisfactory defoliation within 1 wk. after treatment. The latest data that are available were taken 26 wk. after treatment and at that time, picloram and paraquat:picloram were the most effective herbicides. In this case, paraquat did not appear to reduce the activity of picloram, but not enough time has yet elapsed to be certain of the long term results.

TABLE 7.37.--The percentage defoliation of mango resulting from treatments made November 1965 and May 1966. All treatments were applied in a volume of 10 gal. per acre with a telescoping-pole sprayer

Treatment date and herbicide	Rate	Defoliation, weeks after treatment			
		1	4	26	52
November 1965:	Lb. per acre	- - - -	Percent[1]	- - - -	
Picloram	6	1/0	9/0	98/29	100
	12	0/0	15/3	100/62	100
2,4-D:2,4,5-T (1:1)	18	33/0	58/9	60/27	33
Paraquat	9	20/0	75/33	9/9	32
Pyriclor	9	3/0	3/3	1/1	3
Paraquat:picloram (1:1)	12	18/0	75/25	62/58	78
Pyriclor:picloram (1:1)	12	6/0	18/6	60/52	53
May 1966:					
Picloram	6	0/0	2/0	100/85	([2])
	12	2/0	4/0	100/67	([2])
Orange	24	15/0	52/2	88/57	([2])
M-2993	30	4/0	27/0	73/30	([2])
Paraquat:picloram (1:1)	12	30/0	72/8	100/83	([2])

[1] Where double figures are given, that left of the diagonal line represents desiccation plus defoliation; that to the right represents defoliation. Single figures represent defoliation only.
[2] No data.

It seems that picloram is superior to both orange and M-2993.

Pomarrosa

Treatments were applied with a telescoping-pole sprayer for the defoliation and control of pomarrosa in December 1965 and May 1966. The herbicides used were those that had shown promise for the control of other woody species. All of the treatments were made with a telescoping-pole sprayer in a volume of 10 gal. per acre with water as the diluent in most cases. Acetone was used as the diluent for orange and M-2993 because these herbicides were not emulsifiable in water.

None of the herbicides applied in December 1965 caused a high percentage of defoliation within 1 wk. after treatment (table 7.38). One year after treatment, effective defoliation was obtained with picloram and combinations containing picloram. Paraquat, pyriclor, and 2,4-D:2,4,5-T were not effective.

TABLE 7.38.--The percentage defoliation of pomarrosa resulting from treatments made December 1965 and May 1966. All treatments were applied in a volume of 10 gal. per acre with a telescoping-pole sprayer

Treatment date and herbicide	Rate	Defoliation, weeks after treatment			
		1	4	26	52
	Lb. per acre	- - - Percent[1] - - -			
December 1965:					
Picloram	6	1/0	77/25	87/72	90
	12	3/0	52/15	57/52	85
2,4-D:2,4,5-T (1:1)	18	3/0	82/15	75/50	47
Paraquat	9	22/0	33/22	18/12	35
Pyriclor	9	7/0	15/9	27/27	30
Paraquat:picloram (1:1)	12	12/0	88/25	92/82	97
Pyriclor:picloram (1:1)	12	2/0	45/10	72/52	93
May 1966:					
Picloram	6	1/0	53/7	77/77	([2])
	12	2/0	65/15	91/91	([2])
Orange	24	5/0	67/15	60/60	([2])
M-2993	15	0/0	58/15	67/57	([2])
	30	5/0	75/22	87/80	([2])
Paraquat:picloram (1:1)	12	7/0	93/22	92/75	([2])
Orange:picloram (2:1)	12	0/0	70/17	77/70	([2])

[1] Where double figures are given, that left of the diagonal line represents desiccation plus defoliation; that to the right represents defoliation. Single figures represent defoliation only.
[2] No data.

Defoliation 1 wk. after treatment resulting from treatments made in May 1966 were also low. The latest ratings available were made 26 wk. after treatment. At that time, there were no clear-cut differences between treatments, but there seemed to be some advantage for the higher rates of picloram and M-2993. Orange at 24 pounds per acre was no more effective than lower rates of M-2993 and orange:picloram.

Camasey

Treatments were made on camasey with the telescoping-pole sprayer in August and October 1966. All herbicides were applied in a volume of 10 gal. per acre with water as the diluent, except for orange and M-2993 for which acetone was used as the diluent. Herbicides that were evaluated included picloram, orange, M-2993, M-3140, paraquat:picloram, and orange: picloram.

The data from these tests are not included in the report. The latest ratings available were taken 3 mo. after treatment and at that time there was virtually no difference between treatment. All of the herbicides had resulted in a defoliation of 85 percent or more. Additional information on the reaction of camasey to various herbicides can be obtained in chapter 8 under the discussion of aerial treatments.

Summary of Foliage Treatments

The results obtained on the species discussed in this chapter were surprisingly similar in terms of the most effective herbicides for either short term or long term defoliation. When speaking of rapid defoliation, diquat and paraquat were consistently superior. Several herbicides provided acceptable short term defoliation of huisache and mesquite and combinations including paraquat were effective on yaupon. But in the main, where rapid defoliation of a species was obtained, paraquat or diquat were among the most effective herbicides. Other chemicals that act specifically as defoliants did not give good results. Included in that class are DEF, folex, and butynediol.

Effective long term defoliation cannot be discussed without indicating the general superiority of picloram. Bromacil was effective for defoliating whitebrush, yaupon, and live oak, but it was not more effective than picloram.

The broad spectrum of woody species susceptible to picloram makes it the single, most important herbicide for woody plant control. A few species tolerate high rates of picloram, but many species tolerate high rates of other herbicides. Thus, the use of picloram is particularly appropriate for the defoliation of forest types characterized by high species diversity. Such forest types are frequently found in tropical environments.

Greater suppression of lateral and basal dormant buds is an added advantage of picloram. Numerous weed scientists have observed a greater degree of sprouting after treatment with phenoxy herbicides than after treatment with picloram. Susceptibility to picloram of a wide array of woody species, equivalent control with lower rates, and greater bud suppression combine to make picloram the best single herbicide available for woody plant control.

Where rapid defoliation is important, picloram is less effective than orange. Another disadvantage of picloram is its persistence in soil (chapter 6). The persistence of picloram in soil is a severe limitation on its use in cultivated crops. There is evidence, however, indicating that it is rapidly leached from sandy soils, so the planting of shallow-rooted crops following treatment with picloram may be possible.

Picloram has a low acute oral toxicity. The LD_{50} values for rabbits, mice, guinea pigs, chicks, and rats range from approximately 2 (for rabbits) to 8.2 g. per kg. of body weight (for rats). The chronic toxicity of picloram is also low. Ninety-day feeding tests on rats indicated that a level of 1,000 p.p.m. in the diet caused no observable adverse effects as judged by the usual chemical and pathological tests. Levels of 3,000 p.p.m. resulted in modest effects on the liver. The results of long term feeding tests of picloram are not yet available.

The effects of herbicidal combinations were varied among species. The most desirable combination is one that would provide both rapid and long term defoliation. For that purpose paraquat:picloram was an obvious choice. In actuality, paraquat:picloram was effective on the yaupon-winged elm-oak association, the mixed hardwoods of the Texas Piney Woods, mango, and pomarrosa, but was not effective on whitebrush, huisache-mesquite, live oak, and guava. It is not possible to predict on what species or under what conditions paraquat:picloram will be effective.

Combinations of picloram with phenoxy herbicides, such as M-2993 and M-3140, were evaluated relatively late in the program, so we do not yet have adequate data on their performance. Preliminary data suggest that both M-2993 and M-3140 are better herbicides than the phenoxy compounds alone. Additional data are given in chapter 8.

The use of surfactants can enhance herbicidal activity markedly; particularly of herbicides that are water soluble. In that regard, X-77 improved the level of defoliation obtained with diquat, paraquat, dicamba, and picloram. The efficacy of surfactants for oil-soluble herbicides is not so well demonstrated. However, all commercial oil-soluble formulations contain surfactants and their usefulness is not open to serious question. Certainly, they do not reduce herbicidal activity.

The date of treatment is an important variable in woody plant control. A species that is highly resistant to a herbicide at one time may be susceptible to the same herbicide at another time. Woody plants are most susceptible to phenoxy herbicides when treated immediately after a period of active leaf development and twig elongation. Susceptibility to picloram extends over a longer period than for the phenoxy herbicides. When treatments cannot be made at the proper time, the date of application is better made too late than too early. The concept of seasonal susceptibility applies not only to woody plants in temperate zones, but also to those in tropical areas where rainfall is seasonal.

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CHAPTER 8

DEFOLIATION OF TROPICAL AND SUBTROPICAL FORESTS BY AERIAL APPLICATION OF HERBICIDES

Th use of aircraft in agriculture and forestry is a standard practice in much of the world. Herbicides and other pesticides, as well as seeds and fertilizers, have been applied aerially in a wide array of solid and liquid formulations. Herbicidal treatments are commonly made on cropland, ditchbanks, utility rights-of-way, grazing lands, and forests for the control of vegetation ranging in growth form from prostrate herbs to large trees. The taxonomic diversity of the vegetation is even more outstanding than growth form. If an effective treatment exists for the chemical control of a plant species, that treatment can be applied from aircraft.

Many types of aircraft are used for aerial application of herbicides. Helicopters and small, single-engine airplanes are used for most of the agricultural work. When large acreages are treated, larger single-engine aircraft such as the TBM, or multi-engine aircraft are commonly used. The type of aircraft to be used is dictated by the requirements of the job, rather than effectiveness of the application.

A unique advantage of aerial application is that large areas can be treated in a short time. Moreover, growth form of the vegetation is not a limiting factor, and topography poses less of a problem for aircraft than for ground equipment.

Aerial treatments in Texas were applied on winged elm, live oak, oak-pine, and on mixed brush in the Gulf Prairie (fig. 3.6).

Aerial treatments in Puerto Rico were made on three sites in the Moist Coastal Forest, two sites in the Upper Cordillera, and three sites in the Evergreen Rain Forest of the Lower Luquillo Vegetative Zone (fig. 3.3).

The objectives of the treatments in both Texas and Puerto Rico were (1) to evaluate different rates of a number of herbicides for their effectiveness in defoliating and killing woody plants and (2) to compare the most promising herbicides with orange or purple. The results were evaluated for rapid defoliation and the length of time that control was maintained. The treatments in Texas were made with fixed-wing aircraft; those in Puerto Rico with a helicopter.

Treatments in Texas

Live Oak, Gulf Prairie

Several experiments were conducted involving aerial application of herbicides for the defoliation and control of live oak. Treatments for the first experiment were made on May 14, 1964. A fixed-wing aircraft was used to spray 5-acre plots 160 ft. wide and 1,320 ft. long. There were four, 40-ft. swaths for each plot. Silvex, 2,4,5-T, picloram, and a mixture of 2,4,5-T and dichloroprop were tested at various rates. The phenoxy herbicides were applied in an oil-in-water emulsion. Picloram was applied in water. Volume for each of the treatments was 7 gal. per acre.

Plots treated with 1 and 2 lb. per acre of the four herbicides were retreated with the same herbicides in May 1965. Plots treated with 8 lb. per acre were not retreated.

The percentages of defoliation, 1 and 2 yr. after the initial treatment, show clearly that picloram was the most effective herbicide (table 8.1). One pound of picloram caused greater defoliation than 2 lb. of the other herbicides or 8 lb. applied in a single treatment. One yr. after the retreatment, the percentages of defoliation for both rates of picloram were more than 90 percent.

Silvex was the poorest of the herbicides tested for the control of live oak. Eight pounds per acre provided 71 percent defoliation 1 yr. after treatment, but at the end of 2 yr., only 50 percent defoliation. Initial treatments of 1 and 2 lb. per acre, plus a retreatment 1 yr. later at the same rate, was as effective as a single 8-lb. application.

The results obtained with 2,4,5-T and 2,4,5-T:dichloroprop were intermediate between those obtained with silvex and picloram. It is of interest to note that the second treatment with the phenoxy herbicides did not increase the percentage of defoliation appreciably. The second treatment with picloram, on the contrary, increased defoliation about 20 percent.

The second experiment for the defoliation and control of live oak involved treatments applied in July and November 1965. Picloram, 2,4,5-T, and picloram:2,4,5-T were applied to test their relative effectiveness and to gain some insight into seasonal susceptibility. Five-acre plots were used for the July treatments and 8-acre plots for the November treatments. Two replications in a randomized block design were treated on both dates. Ratings of the plots were made in August 1966.

Picloram was the most effective herbicide (table 8.2). A fall treatment with 4 lb. of picloram resulted in a high level of defoliation and only a small percentage of the plants had regrowth. The results obtained with 2,4,5-T were markedly different. One year after the July treatment, 2,4,5-T defoliated 75 percent of the trees, but 93 percent of the plants resprouted. The fall treatment with 2,4,5-T resulted in a defoliation of only 43 percent and 100 percent of the plants resprouted. The combination of picloram and 2,4,5-T was intermediate between the other two herbicides. Defoliation was about the same as that obtained with an equivalent rate of picloram, but more of the trees had regrowth.

The percentage of trees with regrowth (table 8.2) is an important statistic. This experiment and others show that the amount and the rapidity of regrowth on many plants are greater when treated with phenoxy herbicides such as 2,4,5-T, than when treated with picloram. Thus, woody species may be equally susceptible to picloram and 2,4,5-T in terms of defoliation, but less regrowth on plants treated with picloram prolongs the period of effective control.

The data from this experiment and the preceding one suggest that live oak is more susceptible to 2,4,5-T during the summer than in May or November. Picloram, the best

TABLE 8.1.--Percentage of defoliation resulting from aerial applications[1] of herbicides to liva oak

Herbicide	Rata	Defoliation in--	
		May 1965	May 1966
	Lb. per acre	- - -Percent- - -	
Silvex	1	33	45
	2	46	50
	[2] 8	71	50
2,4,5-T	1	65	65
	2	55	68
	[2] 8	61	60
2,4,5-T:dichloroprop (1:1)	1	56	63
	2	71	68
	[2] 8	66	50
Picloram	1	75	93
	2	79	98

[1] Treatments made in May 1964. Plots treated with 1 and 2 lb. per acre were retreated with the same ratea in May 1965.
[2] Not retreated.

TABLE 8.2.--Percentage of defoliation and percentage of treea with regrowth in August of the year after July and November 1965 aerial applications of herbicides to live oak

Herbicide	Rate	Defoliation after treatment in--		Regrowth after treatment in--	
		July	Nov.	July	Nov.
	Lb. per acre	- - - - - - Percent - - - - - -			
Picloram	1	73	62	96	96
	2	88	94	66	61
	4	92	95	61	19
2,4,5-T	2	75	43	93	100
Picloram: 2,4,5-T (1:1)	4	82	94	85	47

TABLE 8.3.--Percentage of desiccation and defoliation resulting from aerial application to live oak in November 1966

Herbicide	Volume	Carrier		Desiccation and defoliation[1] at--			
		Water	Diesel Oil	1 wk.	2 wk.	4 wk.	5 wk.
	Gal. per acre	Gal. per acre	Gal. per acre	Percent			
M-3151	3.0	--	--	26/0	95/62	98/80	80
Picloram, K salt	[2] 1.0	4.0	--	18/0	90/25	94/82	91
	[3] 1.0	4.0	--	19/0	90/25	95/78	85
Picloram, isooctylester	1.0	--	4.0	14/0	93/27	96/68	80
M-3140	1.5	--	--	29/0	88/15	95/78	70
	2.0	--	--	29/0	99/8	95/78	72
	3.0	--	--	46/0	85/45	99/62	82
	1.5	--	0.5	19/0	94/31	96/80	77
M-3060	2.0	2.25	0.75	21/0	90/22	95/50	84

[1] The figure to the left of the slash mark represents the percentage of leaves desiccated and defoliated; that to the right represents the percentage of defoliation. Single figures represent defoliation only.
[2] Surfactant X-77 added at 0.5 percent.
[3] Surfactant DMSO added at 0.5 percent.

herbicide for the control of live oak, was not affected as greatly by season of treatment as was 2,4,5-T. The problem of seasonal susceptibility will be discussed in greater detail at the end of this chapter.

The final test for the defoliation and control of live oak by aerial application was made in November 1966. The objectives were (1) to compare two formulations of picloram with combinations of picloram and phenoxy herbicides, and (2) to test the effect of different carriers and surfactants. Ratings were made 1, 2, and 4 wk. after treatment. Additional ratings will be made in the summer of 1967.

Only data for initial defoliation are available now (table 8.3). A slight advantage was shown for the 3 gal. per acre vol. of M-3140 for observations that were made 1 and 2 wk. after treatment. Four weeks after treatment the defoliation obtained with M-3140 was lower than that obtained with most of the other herbicides.

Huisache and Mesquite, Gulf Prairie

An area near Campbellton, which contained a mixture of huisache and a number of other woody species, was sprayed by aircraft on October 14, 1965. The 4-acre plots were 200 ft. wide and 840 ft. long, providing for five swaths on each plot. Two replications in a randomized block design were treated with a fixed-wing aircraft flying about 10 ft. above the brush.

Extensive defoliation of most species was evident 3 wk. and 6 mo. after treatment. The earlier evaluations were cursory, but detailed evaluations were made in the fall of 1966 (table 8.4). As was the case for most of the foliage treatments, picloram was the best herbicide. Picloram at 2 lb. per acre was as good as, or better than, 2 lb. per acre of 2,4,5-T on all species except persimmon. A combination of 1 lb. of picloram and 1 lb. of 2,4,5-T per acre provided slightly greater defoliation than did 1 lb. of picloram alone, but about the same as did 2 lb. of picloram. Yucca was the only species completely resistant to all of the herbicides tested.

Winged Elm, Post Oak Savannah

Aerial treatments were made in May 1965 to plots lying within an oak-winged elm association. The area had been sprayed with 2,4,5-T for post oak control in 1961 and 1962. Control of the oak was very good, but winged elm had been virtually unaffected. Winged elm trees on the plots ranged from 6 ft. to about 40 ft. Treatments were made on duplicate 5-acre plots with a fixed-wing aircraft. Plots were 200 ft. wide and 1,100 ft. long which permitted five 40-ft. swaths. Picloram in two

TABLE 8.4.--Percentage of defoliation of 15 weed and brush species 1 yr. after October 14, 1965, aerial application

Species	Defoliation 1 yr. after treatment with--				
	2,4,5-T ester (2 lb. per acre)	Picloram (1 lb. per acre)	Picloram (2 lb. per acre)	Picloram (3 lb. per acre)	Picloram: 2,4,5-T ester (1:1) (2 lb. per acre)
	Percent				
Agarito	33	50	--	--	--
Blackbrush	88	85	99	100	98
Catclaw	--	73	--	100	--
Granjeno	83	94	96	99	100
Hog-plum	27	45	96	98	97
Huisache	80	77	90	100	100
Live oak	--	60	40	--	--
Lotebush	23	46	48	65	49
Mesquite	50	55	100	--	98
Persimmon	51	29	44	98	78
Prickly pear	83	96	97	100	100
Tasajillo	--	--	100	--	100
Whitebrush	43	97	100	95	90
Wolfberry	25	57	52	59	67
Yucca	0	0	0	0	--

TABLE 8.5.--The percentage of defoliation and kill of winged elm resulting from May 1965 aerial applications of picloram and 2,4,5-T; data were collected in August 1966

Herbicide	Rate	Carrier	Total volume	Defoliation[1]	Kill
	Lb. per acre		Gal. per acre	Percent	
Picloram	2	Norbak[2]	4.0	99a	98a
		Water	4.0	97a	94a b
Picloram	1	Norbak[2]	4.0	93a b	84a b c
			6.5	91a b	84a b c
Picloram	1	Water	4.0	88a b	77 b c d
			6.5	81 b	68 c d
Picloram	1/2	Water	4.0	81 b	66 d
2,4,5-T	2	Diesel oil-water	4.0	59 c	14 e
			6.5	58 c	30 e

[1] Treatment means are ranked by Duncan's multiple range test at the 5-percent level.
[2] A particulating agent manufactured by Dow Chemical Company.

carriers was compared with 2,4,5-T in an oil-water emulsion. The emulsion used with 2,4,5-T always contained 1 gal. of diesel oil per acre.

The aerial treatments were evaluated in August 1966, two full growing seasons after application (table 8.5). Picloram was the most effective herbicide in terms of both defoliation and the percentage of kill. Even one-half lb. of picloram per acre killed more plants than did 2 lb. of 2,4,5-T.

There were no differences between water and the particulating agent as carriers, or between volumes of 4.0 and 6.5 gal. per acre.

Other studies showed winged elm to be most susceptible to picloram when treatments were made within 60 days after the plants were in full leaf. The highest kill was obtained consistently with applications made just after the plants were fully leafed out or within a period of 30 days thereafter. In contrast, winged elm was relatively more susceptible to 2,4,5-T and dicamba when treatments were made about 45 to 60 days after the plants were leafed out.

Mixed Hardwoods, Piney Woods

Aerial applications were made to mixed hardwoods near Livingston, Tex. in May 1966. The purpose of these tests was to compare three rates of promising herbicides with three rates of orange. The herbicides were applied undiluted at 1.5, 3.0, and 6.0 gal. per acre.

Data on defoliation were collected 1, 2, 4, and 13 wk. after treatment (table 8.6). Paraquat was the only herbicide that did not provide at least 90 percent defoliation after 13 wk. A heavy rain that occurred about 2 hr. after the application of the higher rates of paraquat may be the reason for the poor results obtained with this herbicide. Normally one would expect 6 gal. per acre of paraquat to provide a high degree of defoliation. There was some indication, however, that paraquat was not mobile within the plant because the tops of trees were dead, but the lower branches remained green. This may indicate that paraquat is less effective at low volumes than are systemic herbicides such as picloram or 2,4,5-T. Only paraquat caused appreciable defoliation within a 1-wk. period. At the end of 4 wk., defoliation was somewhat better on plots treated with orange, but results were also good with M-2993 and picloram. At the end of the 13-wk. period, all of the herbicies except paraquat had provided 90 or 95 percent defoliation.

At this point in time, it is not possible to demonstrate a definite advantage for any of the herbicides. The rates used in this test were higher than would be required for control, particularly the rates of orange and M-2993. It is interesting to note that 1.5 gal. per acre of picloram (3 lb.) resulted in a level of defoliation equivalent to that obtained with 1.5 gal. (24 lb.) of orange (fig. 8.1).

It is surprising to see that only a low level of defoliation was obtained with orange within a 2 wk. period. A number of tests in Puerto Rico and also in Southeast Asia indicate that orange is a very rapid defoliant. In this test the low level of defoliation may be an expression of the oak species which formed the dominant part of the forest canopy. Oak species, in general, are notoriously slow in defoliating. Even leaves that have been completely desiccated remain on the plant for long periods unless high winds, rainfall, or some other disturbance causes them to drop.

The plots treated in this test will be evaluated again in the spring and summer of 1967 so that the comparative long term effects of the herbicides can be properly evaluated.

TABLE 8.6.--Percentage defoliation resulting from May 1966 treatments on mixed hardwoods near Livingston, Tex.

Herbicide	Treatment, per acre		Defoliation after treatment at--			
			1 wk.	2 wk.	4 wk.	13 wk.
	Gal.	Lb.	Percent			
Paraquat	1.5	3	50	50	50	20
	3.0	6	30	30	40	40
	6.0	12	30	30	40	20
M-2993	1.5	7.5	10	20	40	95
	3.0	15	10	30	50	95
	6.0	30	20	35	60	95
Picloram	1.5	3	10	20	30	90
	3.0	6	10	20	40	95
	6.0	12	10	35	60	95
Orange	1.5	12	10	30	50	90
	3.0	24	20	40	60	95
	6.0	48	20	40	70	95

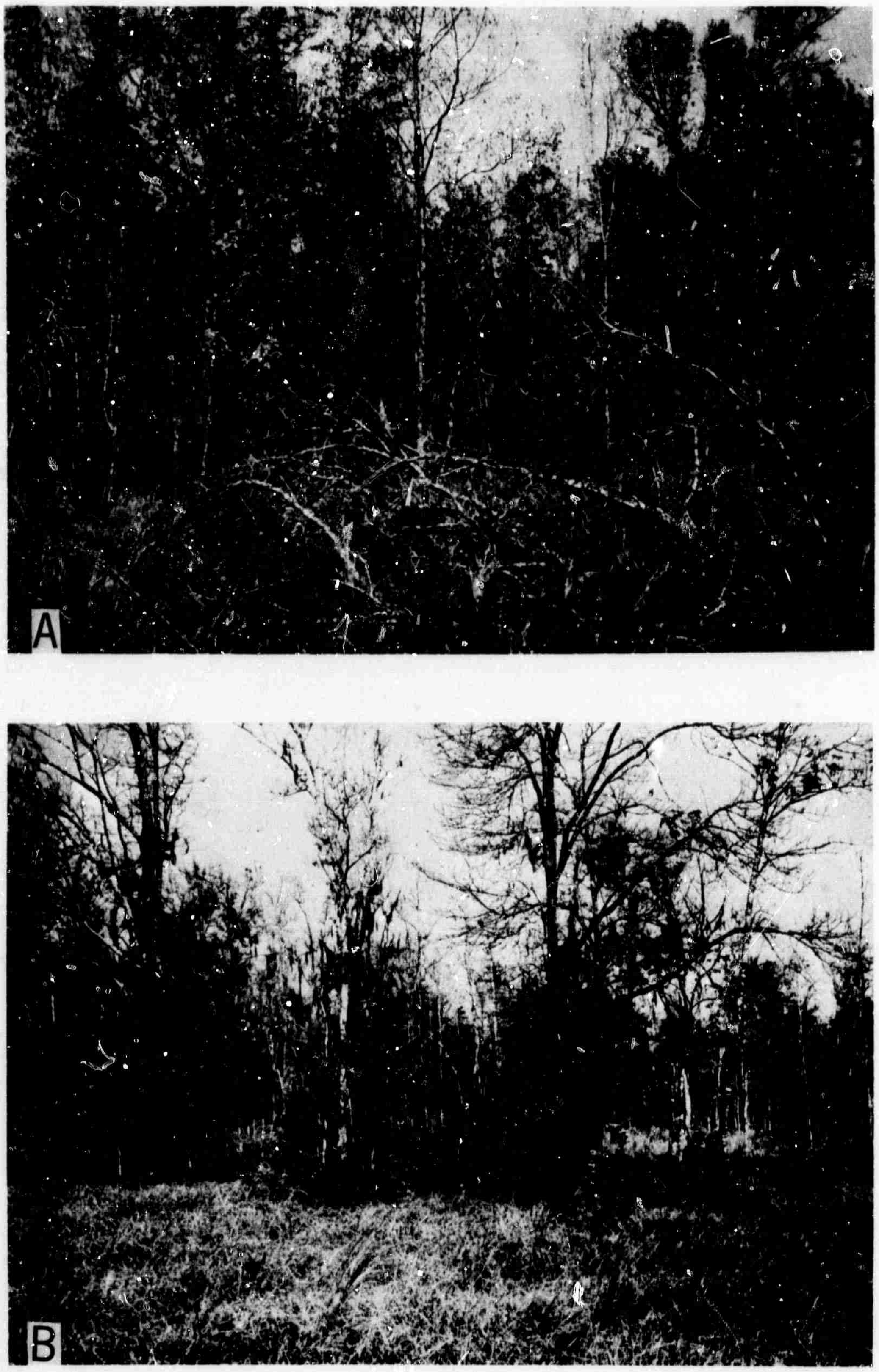

Figure 8.1.--The defoliation of mixed hardwoods obtained 6 mo. after treatment with 1.5 gal. per acre volumes of (A) picloram and (B) orange.

Treatments in Puerto Rico

Eight different aerial treatments were made in Puerto Rico during 1965 and 1966. These included common bamboo, a semievergreen forest, and camasey, in the moist coastal vegetative zone; a palma de sierra forest and a semievergreen forest in the Upper Cordillera; and three sites in a rain forest in the Lower Luquillo Zone. Thus, aerial treatments were made in a variety of vegetative types occurring in a variety of climatic and edaphic environments. The variety involved in the treatments permits a broader assessment of the overall effectiveness of aerial treatments than would have been possible if treatments had been made in only one location.

Common Bamboo, Moist Coastal Zone

Common bamboo located along a stream a short distance south of Mayaguez, was treated on May 6, 1965. The treatments were made with a helicopter calibrated to deliver 10 gal. per acre. Picloram, 2,4-D:2,4,5-T (1:1), dalapon:amitrole-T (2:1), and bromacil: paraquat (2:1) were applied to 75 by 100 ft. plots. There were two, 35 ft. swaths on each plot and the helicopter flew as close to the bamboo as was possible.

Picloram and 2,4-D:2,4,5-T were completely ineffective at all rates (table 8.7). Bromacil: paraquat caused a little defoliation 3 wk. after treatment, but 17 wk. after treatment recovery was complete. Dalapon:amitrole-T was the only herbicide that provided appreciable defoliation. Six pounds per acre of this combination provided reasonably good desiccation and defoliation 17 wk. after treatment and the effect was greater 26 wk. after treatment. Considerable recovery had occurred 52 wk. after treatment on the plot treated with 6 lb. per acre, but additional defoliation had occurred on plants treated with 18 lb. per acre.

The results obtained in these tests were not encouraging. Even though most of the topgrowth was killed, regrowth had started a year after treatment (fig. 8.2). During the next growing season, additional regrowth and new culms would be expected to form a thicket as impenetrable as before treatment. The bamboos are difficult to kill with herbicides, although there is a good deal of differential susceptibility between species. Earlier work in Puerto Rico showed common bamboo to be more

TABLE 8.7.--The percentage of desiccation and defoliation resulting from May 6, 1965, aerial applications of several herbicides on common bamboo

Herbicide	Rate	Desiccation and defoliation[1] at specified times after treatment					
		1 wk.	3 wk.	6 wk.	17 wk.	26 wk.	52 wk.
	Lb. per acre	Percent					
Picloram	2	0	0	0	0	0	0
	6	0	0	0	0	0	0
	18	0	0	0	0	0	0
2,4-D:2,4,5-T (1:1)	2	0	0	0	0	0	0
	6	0	0	0	0	0	0
	18	0	0	0	0	0	0
Bromacil:paraquat (2:1)	2	0	3/0	0	0	0	0
	6	0	0	2/0	0	0	0
	18	0	13/3	5/0	0	0	0
Dalapon:amitrole-T (2:1)	2	0	7/0	5/0	0	0	0
	6	0	5/0	6/0	61/0	70/23	32/10
	18	0	7/0	5/0	63/5	70/27	73/43
Check	--	0	0	0	0	0	0

[1] The figure to the left of the slash mark represents the percentage of leaves desiccated and defoliated; that to the right represents the percentage of defoliation. Single figures represents defoliation only.

Figure 8.2.--The appearance of common bamboo: A, Before and B, a year after treatment with 18 lb. per acre of dalapon:amitrole-T (2:1).

resistant than any other bamboo species tested (2).

We have no knowledge of whether bamboo might be more susceptible during another season of the year. New culms of bamboo are initiated and make their growth during the summer months. It is during this period that the maximum amount of herbicidal absorption would be expected. The herbicide would have to be translocated to the roots, however, to kill the plants. This latter point is true regardless of the season of application, because the amount of regrowth resulting from cutting is about the same, regardless of what month the cutting is done (9). Species that are vigorous sprouters are usually difficult to control and bamboo is no exception. It should be remembered, however, that common bamboo is one of the most resistant species. Other species, such as Dendrocalamus strictus and Sinocalamus oldhami are quite susceptible.

Semievergreen Forest, Moist Coastal Zone

Treatments were made in a semievergreen forest near Lake Guajataca. Treatments were made with a helicopter calibrated to deliver 10 gal. per acre. The 1-acre plots were 175 ft. wide and 149 ft. long permitting five swaths for each plot. Picloram, dicamba, 2,4-D:2,4,5-T (1:1), and paraquat, followed 1 wk. later with picloram pellets, were evaluated on two replications in a randomized block design. Water was used as a diluent for all treatments. Each plot was treated at a volume of 10 gal. per acre.

Plots were evaluated by estimating the percentage of desiccation and defoliation on marked trees within a belt transect located diagonally across each plot. The same trees were used for each rating.

The combination of paraquat and picloram pellets was made with the thought that paraquat would provide very rapid defoliation, and that the picloram pellets would prevent the regrowth that normally follows treatments with paraquat. In that way it would be possible to have both rapid defoliation and long term defoliation.

Paraquat provided the most rapid defoliation. One week after treatment, 15 percent of the leaves were defoliated and an additional 45 percent were completely desiccated. That level of defoliation and desiccation provided a striking change in the aerial aspect of the vegetation. Prior to treatment, the canopy was closed; 1 wk. after treatment the ground was clearly visible in many places.

Fifty-two weeks after treatment the highest percentage of defoliation was obtained with 18 lb. per acre of picloram (table 8.8). A high

TABLE 8.8.--The percentage of desiccation and defoliation resulting from aerial application of herbicides on a semievergreen forest near Lake Guajataca in the moist coastal zone

Herbicide	Rate	Desiccation and defoliation[1] at specified times after treatment					
		1 wk.	2 wk.	4 wk.	13 wk.	26 wk.	52 wk.
	Lb. per acre	Percent					
Picloram	6	29/10	41/19	49/36	63	67	61
	18	27/9	43/14	55/30	67	76	83
Paraquat + picloram-pellets	18 + 10	60/15	75/23	81/50	77	79	79
Dicamba	6	7/1	17/6	24/14	27	23	21
	18	23/1	13/19	55/29	65	77	75
2,4-D:2,4,5-T (1:1)	6	25/1	27/11	33/21	45	45	37
	18	10/3	19/7	30/7	45	54	49

[1] The figure to the left of the slash mark represents the percentage of leaves desiccated and defoliated; that to the right represents the percentage of defoliation. Single figures represent defoliation only.

level of defoliation was also obtained with dicamba and the paraquat:picloram-pellet combination. The 2,4-D:2,4,5-T combination was much less effective. Six pounds per acre of picloram gave better control than did 18 lb. per acre of 2,4-D:2,4,5-T.

The results of this test indicate that air-to-ground obscuration is decreased markedly by desiccation of the leaves even though the level of defoliation is still quite low. The data in table 8.8 suggest that rapid reductions of air-to-ground obscuration might better be predicated on desiccation of leaves rather than defoliation. Desiccation and defoliation are two separate processes. Desiccation involves only a withdrawal of water from leaf tissue which results in the destruction of chlorophyll and a shrinkage of the total leaf area. Defoliation, on the other hand, does not occur until after the formation of an abcission layer which weakens the petiole and causes the leaf to drop off. Defoliation usually requires more time than does desiccation. Thus, when marked reductions of obscuration are desired within a period of several days or, at best, within 6 or 7 hr., desiccation is a much more logical objective than is defoliation.

Camasey, Moist Coastal Forest

A dense stand of camasey near Mayaguez was treated on July 14, 1965. Several species of camasey were present but Miconia prasina was most common. The treatments were made with a helicopter calibrated to deliver 10 gal. per acre. Because the plots were located on steep slopes, the height of the helicopter while spraying was not constant. Maximum height above the vegetation did not exceed 30 ft., however; and, in most cases, it was not over 10 ft. Because only a limited area was available, single replications of 70 by 100 ft. plots were treated. Picloram, dicamba, 2,4-D:2,4,5-T, paraquat, paraquat:picloram-pellets, pyriclor, and pyriclor:picloram-pellets were tested for the defoliation and control of camasey. Water was used as a diluent and all herbicides except the picloram pellets were applied at 10 gal. per acre.

The desiccating effect from both paraquat and pyriclor was rapid. Within 2 days after treatment, 50 percent of the leaves had been desiccated from a treatment of 12 lb. of paraquat (table 8.9). The combined desiccation-defoliation resulting from a treatment with 12 lb. of pyriclor was 38 percent 2 days after treatment. It is of interest to note that 20 percent of the leaves on the plot treated with 12 lb. of pyriclor had defoliated within the 2-day period. This was the most rapid defoliation obtained from an aerial application. One week after treatment desiccation and defoliation had improved considerably and the percentage of defoliation obtained with 12 lb. of pyriclor was still better than any other herbicide. Two weeks after treatment paraquat and pyriclor were about equal in effectiveness and some defoliation had occurred on plots treated with other herbicides. Four weeks after treatment the highest percentage of defoliation was recorded for the plot treated with 18 lb.

TABLE 8.9.--The percentage of desiccation and defoliation resulting from July 14, 1965, aerial application of herbicides on camasey at specified intervals after treatment

Herbicide	Rate	Desiccation and defoliation[1] of specified times after treatment						
		2 day	1 wk.	2 wk.	4 wk.	13 wk.	26 wk.	52 wk.
	Lb. per acre	-Percent-						
Picloram	6	0	24/3	52/13	72/61	81	87	79
	18	0	3/0	24/3	90/83	93	100	100
Paraquat + picloram pellets	6 + 10	22/0	59/17	55/28	67/56	54	39	20
Paraquat	12	50/0	74/17	85/48	90/78	45	19	4
Pyriclor + picloram pellets	6 + 10	36/0	63/14	66/35	75/68	40	19	4
Pyriclor	12	38/20	76/38	84/54	73/70	6	0	0
Dicamba	6	0	38/9	44/22	52/41	52	72	51
	18	0	11/0	7/0	27/14	35	20	12
2,4-D:2,4,5-T (1:1)	6	0	8/1	30/18	37/20	58	77	84
	18	0	14/1	26/5	26/18	36	54	44

[1] The figure to the left of the slash mark represents the percentage of leaves desiccated and defoliated; that to the right represents the percentage of defoliation. Single figures represent defoliation only.

of picloram. Subsequent observations, at longer intervals after treatment, demonstrated the clear superiority of picloram over the other herbicides. Regrowth occurred rapidly on plots treated with paraquat and pyriclor and 52 wk. after treatment the effect was only negligible. At the end of the observational period, 18 lb. of 2,4-D:2,4,5-T was roughly equivalent to 6 lb. of picloram. Dicamba was less effective.

Picloram pellets applied to plots treated with paraquat and pyriclor did not increase the duration of defoliation in this test. The plots were treated in July, which is a period of high rainfall. It must be assumed that the picloram contained in the pellets was rapidly leached beyond the root zone and, consequently, was not available for absorption when regrowth started.

The appearance of a portion of the camasey area that had been treated is shown in figure 8.3. The dense canopy of camasey before treatment, especially on plots 2 and 4, completely obscured the ground level. Plot Nos. 1 and 3 were treated with 6 and 18 lb. per acre of 2,4-D:2,4,5-T, respectively. It is quite apparent that the level of defoliation was still low but markers identifying plots are clearly visible. Plot No. 2 was treated with 12 lb. of paraquat and plot No. 4 was treated with 18 lb. of picloram. Both of those plots contained a closed canopy of camasey before treatment. At the time the photos were taken, identification markers lying on the ground were clearly visible. Although the level of defoliation for the two plots was about the same 1 mo. after treatment, there is already some regrowth appearing on the plot that had been treated with paraquat. At the end of the observational period, the canopy was again entirely closed on the plot that had been treated with paraquat, but all of the camasey on the plot treated with picloram was dead.

Palma de Sierra, Upper Cordillera

An almost pure stand of palma de sierra is found on the Toro Negro commonwealth forest in the central part of the island. Aerial treatments were made in that forest on May 12, 1965. The spraying was done with a helicopter calibrated to deliver 10 gal. per acre. Height of spraying was generally within 10 ft. of the treetops. Single replications of 70 by 100 ft. plots were treated with picloram, dicamba, 2,4-D:2,4,5-T, and paraquat:bromacil.

Picloram and dicamba were the only herbicides that effectively defoliated palma de sierra (table 8.10). However, 6 lb. of picloram was more effective than 18 lb. of dicamba. The 18-lb. rate of 2,4-D:2,4,5-T resulted in 52 percent defoliation, but the lower rates provided only a negligible effect. All rates of paraquat:bromacil were ineffective.

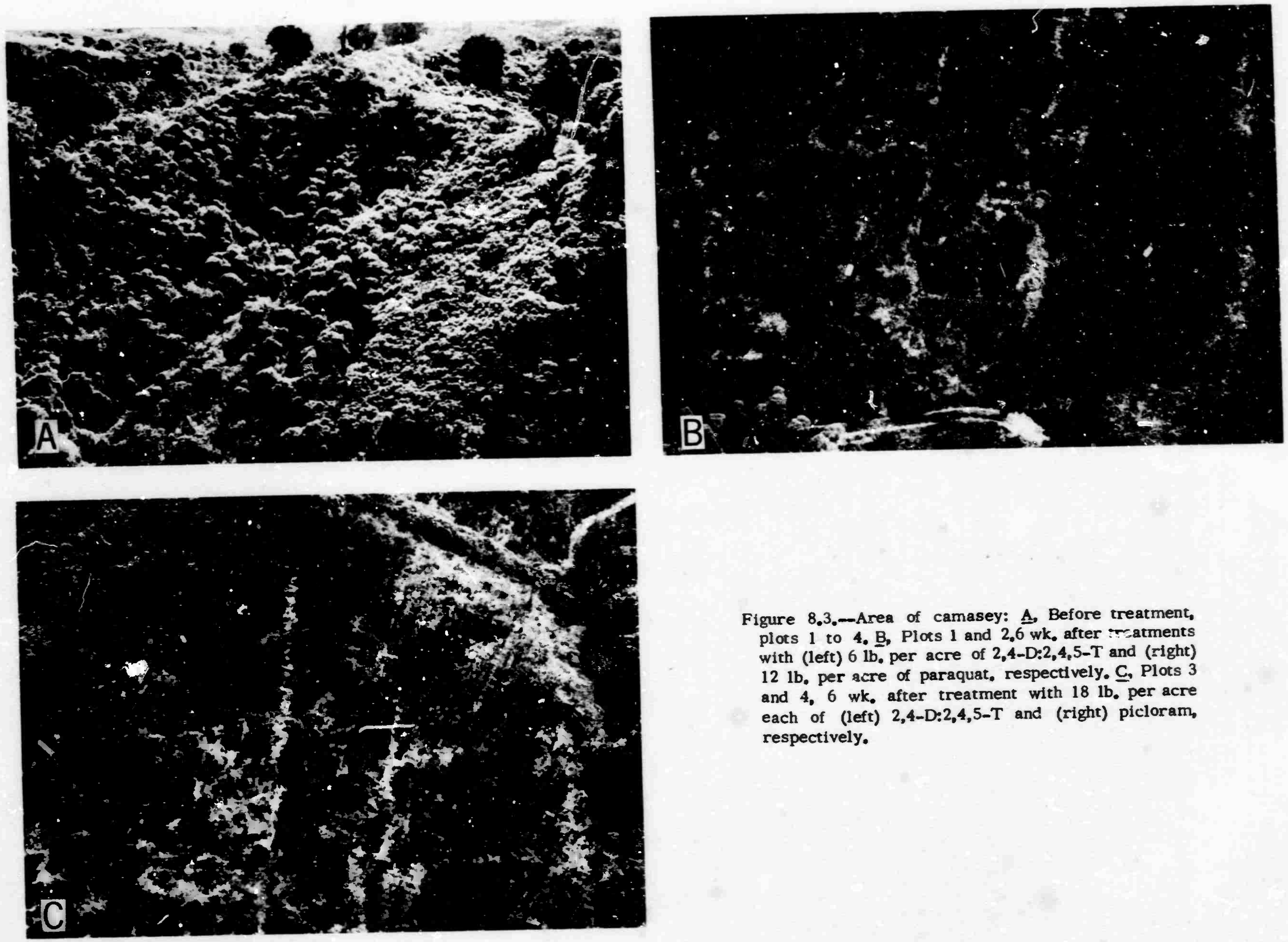

Figure 8.3.--Area of camasey: A, Before treatment, plots 1 to 4. B, Plots 1 and 2,6 wk. after treatments with (left) 6 lb. per acre of 2,4-D:2,4,5-T and (right) 12 lb. per acre of paraquat, respectively. C, Plots 3 and 4, 6 wk. after treatment with 18 lb. per acre each of (left) 2,4-D:2,4,5-T and (right) picloram, respectively.

TABLE 8.10.--The percentage of defoliation resulting from aerial application of herbicides on palma de sierra, May 12, 1965

Herbicide	Rate	Defoliation at specified time after treatment			
		4 wk.	13 wk.	26 wk.	52 wk.
	Lb. per acre	Percent			
Picloram	2	0	0	4	4
	6	0	100	100	100
	18	80	100	100	100
Paraquat:bromacil (2:1)	2	0	0	9	6
	6	0	0	4	12
	18	0	0	3	2
Dicamba	2	0	0	6	6
	6	0	0	4	5
	18	0	48	80	80
2,4-D:2,4,5-T (1:1)	2	0	0	3	12
	6	0	0	7	12
	18	0	26	52	52

Palma de sierra in this test, and in others as well, was not defoliated as rapidly as were other broadleaved species. There was no noticeable effect 2 wk. after treatment, and only the highest rate of picloram resulted in defoliation 1 mo. after treatment. Three months after treatment, however, both 6 and 18 lb. per acre of picloram had provided 100-percent defoliation. Reaction from the other herbicides was even slower.

Palma de sierra was the only palm species present to any extent in all of our aerial spray tests. A few individuals of palma real were present in some other studies. Both of these species were defoliated slowly. Although we suspect that other palm species would also be defoliated slowly, we cannot safely extrapolate beyond our experience with these two species.

Semievergreen Forest, Upper Cordillera

Another aerial application was made in a mixed semievergreen forest of the Upper Cordillera. The treatments were made in August 1966 with a helicopter calibrated to deliver 3 gal. per acre with a swath width of 35 ft. Single replications of 3-acre plots (175 by 745 ft.) were treated with purple, picloram, M-2993, 2,4-D:picloram (4:1)[1], and purple:picloram (2:1). The 6-gal. per acre treatment was applied by passing over the same swath twice at a calibrated rate of 3 gal. per acre. Ratings were made by estimating the percentage of desiccation and defoliation on marked trees within a diagonal transect. Each rating was made from the same set of trees.

All of the herbicides except purple were formulated products. A formulated product contains surfactants that usually increase herbicidal effectiveness (6). Assuming equal effectiveness of the active ingredients of two herbicides, the formulated product would be expected to provide better results.

Long term defoliation data are not yet available for this test. The short term defoliation data (table 8.11) are interesting in that the combination of 2,4-D:picloram at 6 gal. per acre was no more effective than 3 gal. of picloram and considerably less effective than either purple or M-2993. Other evidence from both Puerto Rico and Texas supports the conclusion that 2,4-D:picloram is not as effective as equivalent rates of picloram, 2,4,5-T, or 2,4-D:2,4,5-T. Unfortunately, a plot that was to have been treated with 3 gal. of undiluted M-2993 could not be used because of equipment failure while the plot was being sprayed.

The difference among herbicides is even more striking than suggested in the data given in table 8.11. The photos shown in figure 8.4 were taken 4 mo. after treatment and show the defoliation that was obtained with 3 gal. of purple, 6 gal. of M-2993, and 6 gal. of 2,4-D:picloram. It is clear that 2,4-D:picloram was much less effective than were the other two herbicides.

Evergreen Rain Forest, Lower Luquillo Vegetative Zone

Three separate tests were conducted in the Jimenez section of the Luquillo National Forest. The vegetation type was the same in all cases. Although the objectives of these three tests were the same, different herbicides,

[1] Sold as "Tordon 101" by Dow Chemical Company.

TABLE 8.11.--The percentage of desiccation and defoliation resulting from five herbicides applied as low-volume aerial sprays on a mixed semievergreen forest

Herbicide	Treatment per acre		Desiccation and defoliation[1] at specified times after treatment				
			1 wk.	2 wk.	4 wk.	13 wk.	26 wk.
	Gal.	Lb.	- - - - - - - -	- -	Percent	- -	- - - - - - - -
M-2993	6	30	0/0	26/8	67/50	80/79	83
Purple	3	24	0/0	30/8	63/48	73/71	61
2,4-D:picloram (4:1)	6	15	0/0	35/15	57/37	53/47	52
Picloram	3	6	0/0	29/19	43/38	51/50	48
Purple:picloram (2:1)	3	12	0/0	36/14	44/32	52/48	57

[1] The figure to the left of the slash mark represents the percentage of leaves desiccated and defoliated; that to the right represents the percentage of defoliation. Single figures represent defoliation only.

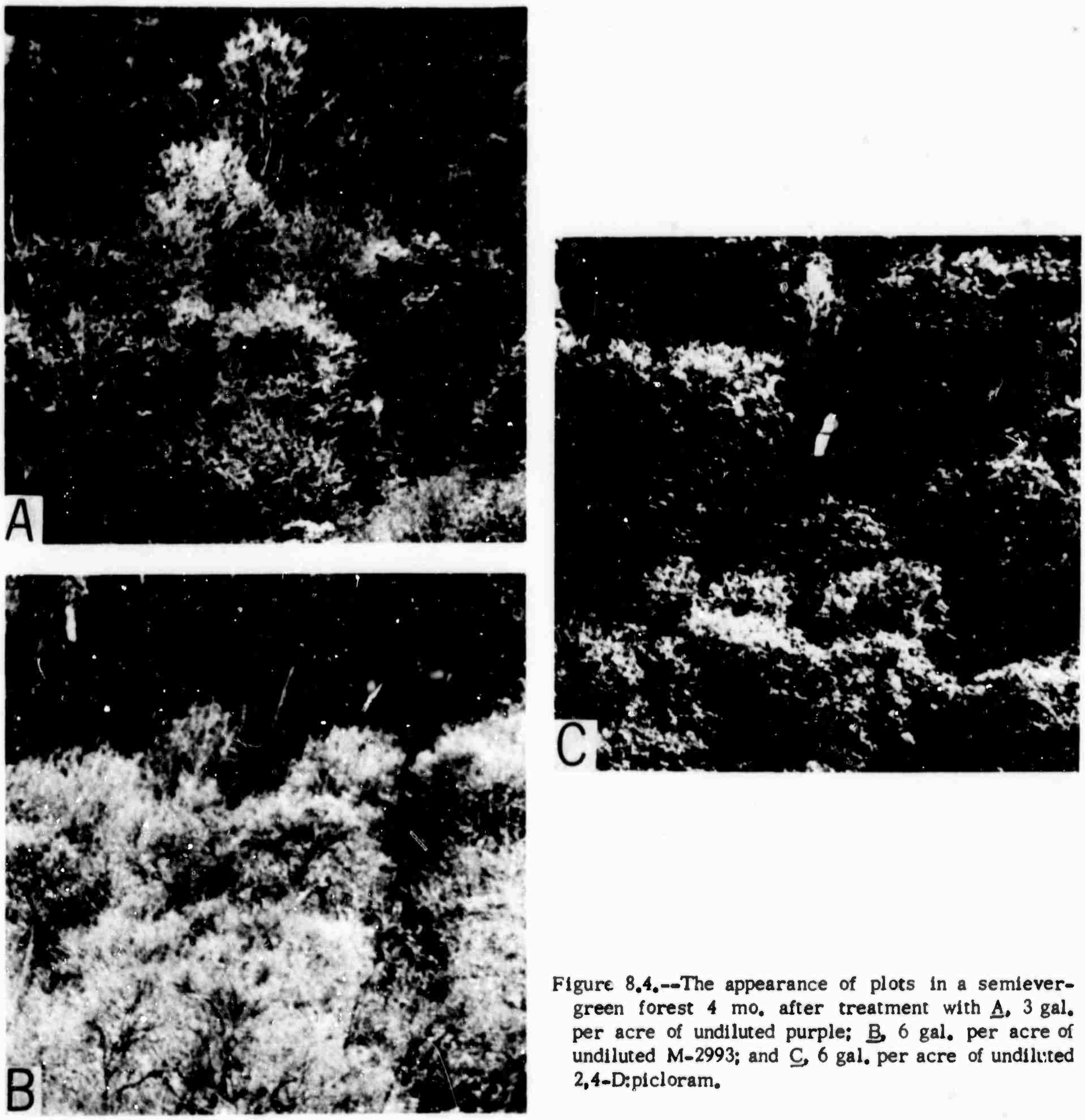

Figure 8.4.--The appearance of plots in a semievergreen forest 4 mo. after treatment with A, 3 gal. per acre of undiluted purple; B, 6 gal. per acre of undiluted M-2993; and C, 6 gal. per acre of undiluted 2,4-D:picloram.

rates, and volumes were tested. Consequently, each of the tests will be discussed separately.

Test No. 1.--Test No. 1 was applied October 14, 1965. The applications were made with a helicopter calibrated for delivering 10 gal. per acre. Two replications of 1-acre plots (175 by 249 ft.) were treated with 2,4-D:2,4,5-T, picloram, paraquat, paraquat: picloram, pyriclor:picloram, paraquat: picloram pellets, and pyriclor:picloram pellets.

The treatments were applied under extremely adverse conditions. Rain was falling when the helicopter arrived and spraying was started soon after the rain stopped. In several instances a light rain shower started as the last swath for a treatment was being sprayed or shortly thereafter. When rain interrupted, we suspended the spraying until dripping from the leaves stopped. Thus, treatments were made immediately before and shortly after light showers. There was virtually no wind and the relative humidity was at, or near, 100 percent all day. This test represents a condition in which wind and relative humidity were optimum for aerial applications, but the intermittent rainfall was considered to be suboptimum.

Evaluations were made by estimating the percentage of desiccation and defoliation of marked trees in a belt transect located diagonally across each plot. All trees within the transect greater than 1 in. d.b.h. were marked so that the trees from which ratings were made were representative of the species diversity in the plot as a whole. Ratings were made from the same trees on each observation date.

The best herbicide in this test, in terms of both initial and long term defoliation, was paraquat:picloram (table 8.12). Other treatments that provided 70 percent or greater defoliation 1 yr. after treatment were picloram at 6 and 12 lb. per acre; pyriclor + picloram pellets at 9 + 10 lb. per acre; and 2,4-D:2,4,5-T (1:1) at 18 lb. per acre. Observations of the plots were also made 1 and 2 days after treatment, but they are not shown in table 8.12 because there was no effect, or at very best, a very slight effect on the second day.

Maximum defoliation occurred within 6 mo. after treatment. Little regrowth was evident in the next 6 mo. except for the plots treated with paraquat.

Test No. 2.--The second test was applied in the Jimenez area of the Luquillo National Forest on April 1, 1966. Treatments were made with a helicopter calibrated to deliver either 1.5 or 3 gal. per acre on a swath width of 35 ft. Six gal. per acre were applied by spraying twice over each swath on a plot at a calibration of 3 gal. per acre. Duplicate 1-acre plots were treated with undiluted orange, picloram, M-2993, and paraquat.

The treatments were evaluated by estimating the percentage of desiccation and defoliation

TABLE 8.12.--The percentage of desiccation and defoliation resulting from aerial application of seven herbicides on rain forest vegetation at specified intervals after treatment

Herbicide	Rate	Desiccation and defoliation[1] at specified times after treatment					
		1 wk.	2 wk.	4 wk.	13 wk.	26 wk.	52 wk.
	Lb. per acre	Percent					
2,4-D:2,4,5-T (1:1)	18	2/0	17/4	66/45	75/73	71	70
Picloram	6	2/1	14/5	55/41	77/74	79	79
	12	5/1	35/13	61/48	79/74	75	76
Paraquat	6	15/5	29/13	43/38	40/39	39	27
Paraquat:picloram (1:1)	12	28/11	53/19	78/63	90/85	89	87
Pyriclor:picloram (1:1)	12	19/7	25/12	49/35	61/55	69	69
Paraquat + picloram pellets	9 + 10	19/11	31/19	50/37	49/49	49	57
Pyriclor + picloram pellets	9 + 10	11/3	37/22	65/57	63/62	71	71

[1] The figure to the left of the slash mark represents the percentage of leaves desiccated and defoliated; that to the right represents the percentage of defoliation. Single figures represent defoliation only.

of trees greater than 1 in. d.b.h. in a belt transect located diagonally across each plot. The trees were representative of species diversity in the plot as a whole and they were marked so that the same set of trees was used for each rating.

Some desiccation was noted 2 days after treatment, but the effect was not great enough to be recorded. One week after treatment the percentage of desiccation was greatest on the plot treated with 6 gal. of paraquat (table 8.13). The percentage of desiccation and defoliation obtained from 3 gal. of paraquat was approximately equal to that obtained from 6 gal. of orange. Maximum defoliation from paraquat was obtained 4 wk. after treatment, but maximum defoliation from the other herbicides was not obtained until 13 wk. after treatment. It is of interest to note that the reduction of defoliation between 13 and 26 wk. after treatment with the 6-gal. volumes was 20 percent for orange, 7 percent for picloram, and 4 percent for M-2993. That is indicative of the greater bud suppression obtained with picloram. The regrowth of woody species following treatment with herbicides was always greater when treatments were made with phenoxy herbicides than when treated with picloram. For this reason picloram is a much more effective herbicide for long term defoliation.

The greater bud suppression obtained with picloram is particularly evident in the rating made 1 yr. after treatment. Considerable refoliation had occurred on plots treated with orange, but only slight refoliation occurred on those treated with picloram and M-2993. The 12-lb. rate of picloram was the only treatment with which defoliation was maintained above 70 percent 1 yr. after treatment.

Defoliation greater than 70 percent reduced obscuration enough so that the ground could be seen easily. The height of the canopy in this forest was about 70 ft. and tree density was high.

Test No. 3.--The third test in the rain forest of the Luquillo National Forest was applied October 13, 1966. The same type of equipment and procedures were used as in Test No. 2, except that single 3-acre plots were used instead of two replicates of 1-acre plots. Undiluted orange, picloram, M-2993, and M-3140 were evaluated. Climatic conditions were ideal when the treatments were applied, but rain occurred about 3 hr. later. An estimated 2 in. of rain fell during the 24 hr. after treatment.

Surprisingly, the most rapid defoliation was obtained with picloram (table 8.14). This is in contrast to other treatments where a more rapid response was usually obtained with orange. Picloram and M-2993 were most effective 13 wk. after treatment and the same

TABLE 8.13.--The percentage of desiccation and defoliation resulting from four herbicides applied as low-volume aerial sprays on rain forest vegetation

Herbicide	Treatment		Desiccation and defoliation[1] at specified times after treatment					
	Gallon per acre	Pound per acre	1 wk.	2 wk.	4 wk.	13 wk.	26 wk.	52 wk.
			Percent					
Orange	1.5	12	9/3	53/28	69/61	65	52	38
	3.0	24	19/8	73/32	89/73	79	66	55
	6.0	48	28/10	79/37	89/75	91	71	61
Picloram	1.5	3	8/0	24/14	34/[illegible]	29	27	30
	3.0	6	8/0	51/21	70/52	80	60	55
	6.0	12	19/9	51/22	78/66	83	76	75
M-2993	1.5	7.5	7/3	25/14	42/39	52	40	45
	3.0	15	3/0	25/5	39/32	42	46	51
	6.0	30	7/0	38/13	62/45	77	73	69
Paraquat	1.5	3	15/9	25/18	27/25	19	9	10
	3.0	6	29/13	51/29	68/63	51	41	31
	6.0	12	38/23	53/35	60/56	43	15	17

[1] The figure to the left of the slash mark represents the percentage of leaves desiccated and defoliated; that to the right represents the percentage of defoliation. Single figures represent defoliation only.

TABLE 8.14.--The percentage of desiccation and defoliation resulting from six herbicides applied as low-volume aerial spray on rain forest vegetation

Herbicide	Treatment		Desiccation and defoliation[1] at specified times after treatment				
	Gallon per acre	Pound per acre	1 wk.	2 wk.	4 wk.	13 wk.	26 wk.
			Percent				
M-3140	1.5	7.5	0/0	6/4	4/3	6/6	11/11
M-3140 + Diesel oil (1:1)	3	7.5	0/0	27/13	50/41	53/48	60/58
M-3140	3	15	0/0	28/15	49/47	72/68	80/78
Picloram	3	6	15/6	46/26	75/60	88/84	89/85
M-2993	3	15	1/0	35/17	70/52	86/79	91/86
Orange	3	24	3/1	35/20	61/46	68/62	77/75

[1] The figure to the left of the slash mark represents the percentage of leaves desiccated and defoliated; that to the right represents the percentage of defoliation. Single figures represent defoliation only.

was true 26 wk. after treatment. Three gallons of orange and 3 gallons of M-3140 were approximately equal in effectiveness. It is of extreme interest to note that M-3140 at 1.5 gal. per acre resulted in only a very low defoliation. When 1.5 gal. of M-3140 were combined with 1.5 gal. of diesel oil, however, the percentage of defoliation was markedly increased. This suggests the possibility that a volume of 1.5 gal. per acre is too low to be effective, but that the same amount of herbicide applied in the volume of 3 gal. per acre, does a reasonably good job of defoliation. However, additional research is needed to clarify the point. Volumes of 1.5 gal. per acre of other herbicides provided more defoliation in Test No. 2 than in Test No. 3. Other factors may have been confounding the results in this test. It is also of interest to note that 6 pounds of picloram were more effective than 24 pounds of orange in this test.

Figure 8.5 shows the defoliation and the consequent reduction in the level of obscuration 1 mo. after treatment for a plot treated with 3 gal. per acre of orange. Plot defoliation at that time was only 46 percent with an additional 15 percent of the leaves desiccated. It is clear that air-to-ground visibility is not greatly improved when defoliation is less than 50 percent.

Discussion of Aerial Applications

There are a number of considerations that apply to all of the aerial tests that were made. It is important that these considerations be discussed so that the results from the individual tests can be interpreted in terms of a broad background knowledge in aerial spraying, rather than within the confines of individual experiments. Some of these considerations have been discussed in publications by many authors; other considerations have been published a few times; and still other considerations, well known by people experienced in the aerial application of herbicides, have not yet been published.

The height at which an aircraft is flying when herbicides are applied has an important bearing on the defoliation and control of the vegetation that is ultimately obtained. Hyder (4) found that much better control of big sagebrush was obtained when an aircraft was flying 10 ft. above the brush than when flying 50 ft. above the brush. In like manner Tschirley (10) showed that significantly greater control of mesquite was obtained when applications were made from treetop level as opposed to 50 ft. above treetop level.

Evaporation, spray drift, and air turbulence are probably the most important factors that

Figure 8.5.--The defoliation (46 percent) obtained 1 mo. after treatment with 3 gal. per acre of orange.

cause differential effectiveness when flying at different heights. Evaporation is particularly important when aqueous spray solutions are applied in a dry climate. For example, a 150 μ droplet of water in an environment of 50 percent relative humidity and 77° F. has a lifespan of about 32 sec. and falls at a rate of 1.5 ft. per second. Evaporation decreases the size of the droplet and slows the rate of the fall. If a 150 μ droplet of water is released from 50 ft. above treetop level, it would not reach even the tops of the trees before evaporation caused its disappearance.

Drift is also an important factor influenced by the height from which an aircraft is spraying (8). For example, a 200 μ droplet would drift 9 ft. while falling 20 ft. in a lateral airflow of 1 mile per hour. A 150 μ droplet would drift 21 ft. while falling 14 ft., and at that time the droplet would have disappeared (fig. 8.6).

Many fine droplets (200 μ or less) are formed when a liquid is released from aircraft. Since fine droplets are influenced so markedly by evapoaration and drift, the higher an aircraft flies, the less probability there is of a droplet reaching the vegetation. A steadily decreasing percentage of defoliation is probably an unvoidable consequence of increasing height of spray applications. All of the aerial treatments in Puerto Rico and Texas were applied near treetop level. Had applications been made at greater heights, the levels of defoliation reported probably would have been lower.

Droplet size is vitally important from the standpoint of evaporation and drift. Concern about droplet size should not overshadow the importance of droplet distribution, however. The number of droplets deposited per square inch of leaf surface has a striking effect on the response of plants to herbicides. Behrens (1) found that the effectiveness of 2,4,5-T increased greatly as the number of droplets increased from 9 to 72 (per square inch), while the amount of 2,4,5-T remained constant. A further increase of number of droplets did not increase effectiveness. It is important, therefore, to bear in mind that plants and the physical environment are both important variables. One cannot be emphasized at the expense of another.

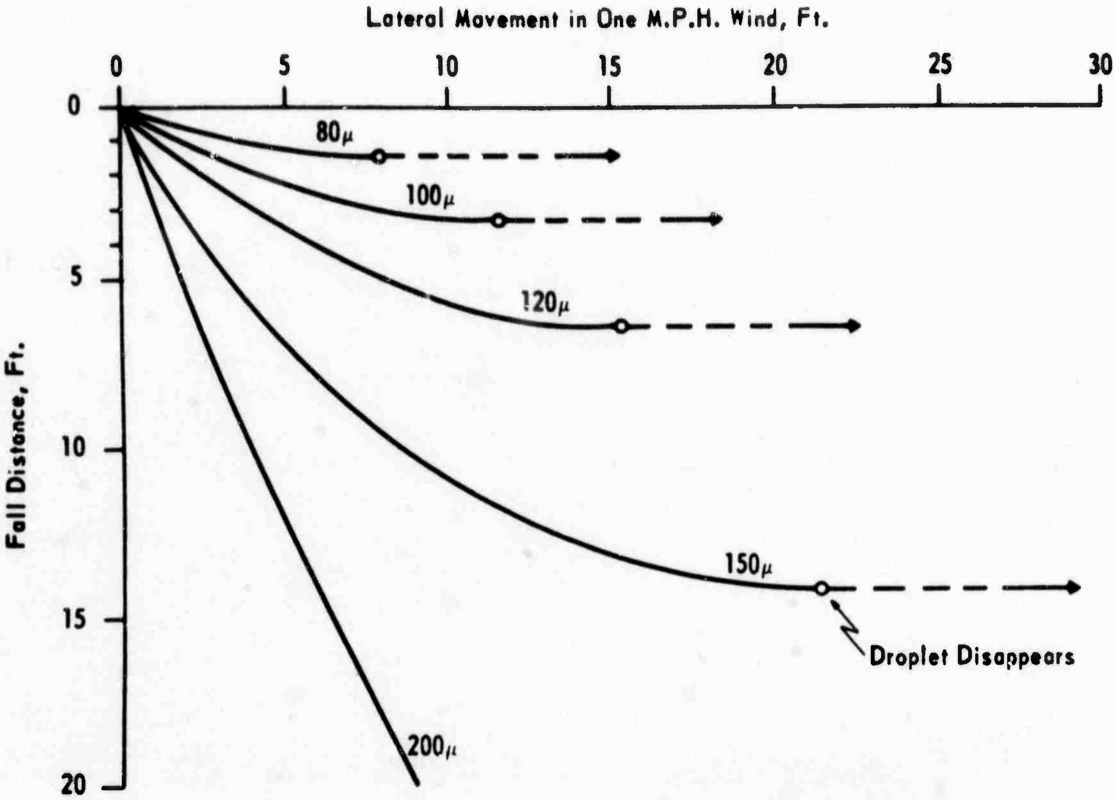

Figure 8.6.--Evaluation of water spray drift in a 1 mile per hour wind, 77° F., and 50 percent relative humidity (8).

Air turbulence resulting from low-flying aircraft is an important factor in providing distribution of a spray solution throughout a vegetative profile. When all droplets are falling in a straight line, most of them will be intercepted by the upper portions of a forest canopy. Turbulence from the aircraft will help to distribute the droplets throughout the canopy.

The type of aircraft used to dispense spray solutions are not important on level terrain. In rolling, hilly country or in mountains better results will be obtained from smaller aircraft simply because they can follow the contour more closely and thus the height of flying will not be so variable. If large aircraft must be used in mountainous topography, an increased volume and a larger droplet size may compensate for the greater distance of droplet fall. Without such compensation the degree of defoliation and control may be reduced.

A great deal of work in temperate zones has shown that a woody species is susceptible to a given herbicide during one season of the year, but may be quite tolerant to the same herbicide if applied in a different season of the year (3, 5, 7, 11). The season of greatest susceptibility is usually defined in terms of a calendar date, or the stage of growth of the species to be controlled, or of associated vegetation. Research on guava, which was reported in chapter 7, showed that tropical species are also more susceptible during some seasons than others. Woody plants are almost invariably most susceptible to herbicides immediately after a period of rapid growth. For example, the most susceptible period for mesquite is defined as occurring when leaves have reached full size but have not yet hardened off, and terminal twig elongation has stopped. Maximum translocation to the roots will occur at this time. Deciduous or semideciduous woody species, regardless of where they grow, can be expected to exhibit differential seasonal susceptibility, because they will have a period of rapid foliar development. The situation is quite different in a tropical evergreen rain forest where neither moisture nor temperature limit plant growth during any part of the year. Although there may be small peaks of seasonal susceptibility among the species found in a tropical rain forest, the effect would not be as pronounced as it is for deciduous and semideciduous species.

The herbicidal rates necessary for the defoliation of woody plants in tropical Puerto Rico were much higher than those needed in subtropical Texas. The difference is not due to latitude nor to the species themselves. It is much more probable that woody plants in a wet environment are more tolerant of herbicides than those in a dry environment. Although initial defoliation may be equally good in wet and dry areas, the woody plants in wet areas have a greater potential for recovery than do those in dry areas. Another possible reason for higher rates being necessary in a wet environment, such as a tropical rain forest, is that species diversity is extremely high. Woody plant control in arid or semiarid areas is usually directed against one or a few species and control measures are geared to account for the relative susceptibility of those few species. In a rain forest, on the other hand, there are many species. Some will be susceptible and others will be resistant to a given herbicide. The rate of herbicide must be based on the most resistant species.

Higher herbicidal rates may be necessary in wet environments because there is a greater vegetative biomass. The biomass of a tropical rain forest is much greater than that of a stand of live oak, for example. Assuming an even distribution of droplets throughout a forest canopy, and a minimum droplet density of 72 per sq. in., a greater biomass would necessarily require a greater volume of spray application.

Many weed scientists have observed that picloram provides greater bud suppression than do the phenoxy herbicides. This is an important consideration because many woody species are vigorous sprouters. Any herbicide that will reduce the amount of sprouting will be distinctly advantageous. Even though some species of woody plants are resistant to picloram, it has a broader spectrum of activity, in terms of both species and season of application, than do the phenoxy herbicides. The advantages of broader spectrum of activity, greater bud suppression, and greater seasonal latitude make picloram a highly desirable herbicide.

Combinations of paraquat and picloram have given both good and poor results in Puerto Rico and in Texas. Tests on guava in Puerto Rico showed that the activity of picloram was not enhanced by the addition of paraquat and the rapid defoliation normally obtained with paraquat was lacking. In aerial tests on rain forest vegetation, however, paraquat:picloram was more effective than picloram alone and there was no reduction in the rapidity of defoliation. Tests in Texas showed that paraquat enhanced the activity of picloram in a mixed brush type in eastern Texas, and also in an oak-yaupon association near Carlos, Tex. On the contrary, paraquat reduced the effectiveness of picloram when applied to whitebrush or a huisache-mesquite association. The reasons for the diverse effects obtained with paraquat:picloram combinations are not known.

There is no one best herbicide that would satisfy all the possible requirements. The control of grass usually requires a different herbicide than does the control of woody plants. Rapid defoliation requires a different herbicide than does long term defoliation. If a single species is to be controlled, herbicides must be evaluated to determine which is most effective. The research experience in Puerto Rico and in Texas indicates quite clearly that picloram affects a greater number of species than do the other herbicides included in the test program. Picloram also provides control for a longer period. Therefore, picloram would be the best herbicide for use in areas that have a high species diversity and where long term control is desirable. Paraquat would be most desirable in situations requiring rapid defoliation with no thought being given to long term control. If both rapidity of defoliation and long term control are important requirements, a combination of paraquat and picloram should be considered, but there may be specific vegetational associations that will not be responsive. The work that has been conducted under this project has been limited almost entirely to the defoliation and control of woody plants. The control of grasses has been given very little attention. Incidental observations suggest, however, that bromacil is a likely candidate for the long term control of grass species, paraquat for rapid but short term control, and bromacil:paraquat for rapid and long term control.

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CHAPTER 9

EFFECT OF ENVIRONMENT ON DATE OF HERBICIDAL TREATMENT

The seasonal susceptibility of woody plants to herbicides has been established in published literature. There is no longer any question but that the effectiveness of herbicides applied to the foliage of woody plants in temperate zones is markedly influenced by the season in which treatments are made. In most cases, however, the period of maximum susceptibility cannot be defined on so broad a basis as season. The period of maximum susceptibility is frequently of short duration. Various investigators have defined that period on the basis of climatic events; availability of soil moisture; phenologic development of the woody species itself or of associated vegetation; or by a calendar date based on the number of days after a specific phenologic stage--usually the beginning of leaf development in the spring.

The validity of the concept of seasonal susceptibility is emphasized by its applicability to many woody species growing in a variety of climatic and edaphic environments. A good example is afforded by three varieties of mesquite that are geographically distributed from the semiarid areas of Arizona and New Mexico to the Southern Great Plains of Texas. The precise definitions of the period of maximum susceptibility vary from State to State, but all are predicated on phenologic development either directly or indirectly (3, 9, 10). The most effective control with 2,4,5-T is obtained at a time when leaves have reached full size and terminal twig elongation has stopped.

Post oak and blackjack oak are most susceptible if treated during a period of active growth after the leaves are full size (1). Big sagebrush is a relatively susceptible woody species but it, too, is seasonally susceptible. The effective spraying season begins when the first new leaves are as large as old leaves carried overwinter, or when Sandberg bluegrass has heads emerging from the leaf sheaths (4). Rabbitbrush is most susceptible if treated after new twig growth exceeds 3 in. in length and when large bunch grasses are heading out. Earlier applications kill the active growing tissues but allow lateral and basal sprouting. Effectiveness of the herbicides drops as soil moisture is depleted in the surface 10 in. (4). The control of chamise is most effective when treatments are made in the spring before soil moisture has been greatly reduced (5).

Many other examples of the seasonal susceptibility of woody species to herbicides could be given. However, the general conclusions would be the same as for the examples cited above. The important point illustrated by the examples is the recurrence of similar phenologic and soil moisture conditions as requirements for defining the period of maximum susceptibility. Leaves that are full size, the cessation of terminal growth, and soil moisture adequate for plant development are factors that have become commonplace for defining the period of maximum susceptibility. It is important to remember, however, that most of the published literature on seasonal susceptibility has been limited to the response of woody plants to phenoxy herbicides. Much less is known about the reaction of woody plants to other herbicides. In addition, the research on seasonal susceptibility has been done in temperate rather than tropical zones. The work to be reported in this chapter extends our information to tropical areas and to herbicides other than those of the phenoxy group.

Winged Elm

Picloram, dicamba, and 2,4,5-T were applied at 2-wk. intervals to small plants of winged elm. The herbicides were diluted in water and applied at a volume of 20 gal. per acre with a portable, compressed air sprayer equipped with a three-nozzle boom. Each treatment was applied to 15 plants located at random in three-plant groups.

The results of the study (table 9.1) show clearly that winged elm is seasonally susceptible. For dicamba and 2,4,5-T, the percentage of defoliation increased gradually, reaching a peak with the treatment on May 15. The percentage of defoliation decreased gradually for treatments made after that date. Picloram was about equally effective from April 1 through June 1, but the percentage of defoliation decreased markedly after the June 1 date.

Winged elm appears to have the same period of susceptibility to dicamba and 2,4,5-T, but the period of maximum susceptibility to picloram is much broader. Early treatments with picloram caused a high percentage of defoliation, whereas the effect from dicamba and 2,4,5-T was negligible. It is not clear at this time whether winged elm is susceptible earlier in the season to picloram than to the other two herbicides, or whether the period of maximum susceptibility to picloram is simply broader. The data do show that winged elm is seasonally susceptible and that the period of maximum susceptibility is not the same for all herbicides.

TABLE 9.1.--The percentage of defoliation of winged elm resulting from treatments with picloram, dicamba, and 2,4,5-T. Treatments were applied in 1965 and evaluated in July 1966

Treatment date	Rate	Defoliation after treatment with--		
		Picloram	Dicamba	2,4,5-T
	Lb. per acre	Percent		
Apr. 1	1	95	10	16
	2	100	26	27
Apr. 15	1	94	18	28
	2	100	22	61
May 1	1	80	15	43
	2	96	21	49
May 15	1	93	35	71
	2	92	55	88
June 1	1	85	25	32
	2	93	29	64
June 15	1	41	16	23
	2	67	25	30

Yaupon

Yaupon was treated with 2 pounds per acre of picloram, dicamba, and 2,4,5-T at 15-day intervals beginning October 1, 1964, and continuing through July 1, 1965. The herbicides were diluted with water and applied at a volume of 20 gal. per acre. The treatments were made with a portable, compressed-air sprayer equipped with a three-nozzle boom. Fifteen plants in randomly located three-plant groups were sprayed for each treatment.

The data obtained in this study are similar to those obtained in the experiment on winged elm. The pattern of susceptibility was essentially the same for dicamba and 2,4,5-T. Maximum susceptibility to picloram occurred earlier in the season and extended over a longer period of time (table 9.2). Picloram was also the most effective herbicide, followed by 2,4,5-T and dicamba.

The results obtained from the experiments on winged elm and yaupon add two more temperate zone species to the list of those known to exhibit seasonal susceptibility. Of greater importance is the fact that the period of maximum susceptibility to picloram occurs earlier and extends over a longer period of time than for either 2,4,5-T or dicamba. This fact has important practical considerations.

TABLE 9.2.--The percentage defoliation of yaupon resulting from treatments with 2 lb. per acre of picloram, dicamba, and 2,4,5-T. Treatments were made at 15-day intervals from October 1, 1964, to July 1, 1965. Treatments were evaluated in July 1966

Treatment date	Defoliation after treatment with--			Treatment date	Defoliation after treatment with--		
	Picloram	Dicamba	2,4,5-T		Picloram	Dicamba	2,4,5-T
	Percent				Percent		
Oct. 1	22	19	30	Mar. 1	83	29	42
15	16	10	21	15	96	29	46
Nov. 1	32	18	34	Apr. 1	89	32	54
15	46	36	41	15	90	28	40
Dec. 1	55	18	37	May 1	78	25	63
15	78	12	31	15	86	62	72
Jan. 15	51	15	26	June 1	63	46	74
Feb. 1	29	14	32	15	55	39	73
15	61	14	29	July 1	89	46	73

Guava

The research conducted on the seasonal susceptibility of guava is important because it extends our knowledge to a woody plant growing in a tropical environment, where temperature does not limit plant growth. Guava is a native of tropical America but now has a pan-tropical distribution because of its introduction into other tropical areas throughout the world. It is normally evergreen in tropical areas but may lose some of its leaves during dry periods.

Treatments for this study were made in a small pasture near Mayaguez. Mean annual rainfall for the test site is about 77 in. May through October are the months of highest rainfall with the monthly average being more than 8 in. November through April are drier with monthly averages of less than 6 in. January is the driest month with an average rainfall of 1.90 in.

Temperature and relative humidity are quite constant throughout the year. Mean temperatures taken from the Federal Experiment Station at Mayaguez range from 74.4^{o} in January to 79.6^{o} F. in August. Diurnal fluctuation is much greater than the average annual fluctuation. Relative humidity is high throughout the year. Observations made daily at 0800 during 1964 showed a range from 75 to 90 percent relative humidity.

The principle herbicide used in this study was 2,4-D:2,4,5-T (1:1). Applications were made at approximately 2-wk. intervals at a rate of 6 lb. per hundred gallons. Water was used as the carrier in all treatments. No additional surfactants were added to the spray solution.

Treatments were made with a portable, compressed-air sprayer. A wetting spray at 30 lb. per square inch was applied to 20 plants on each treatment date. Treatments were made between 0800 and 0900 except when there was a heavy dew. Except for the first few dates, all treatments were made by the same man.

Picloram and dicamba were also used in this experiment, but treatments were made at less frequent intervals than with 2,4-D:2,4,5-T. Both picloram and dicamba were applied at the same rate and with the same equipment as was used for 2,4-D:2,4,5-T.

Ratings were made 2 wk., 1 mo., 6 mo., and 1 yr. after treatment. An estimate of percentage of leaves killed was made for each of the 20 plants. The mean percentage of leaves killed actually represents a combination of percentage defoliation and dead leaves that had not yet abscised.

The results of the treatments with 2,4-D:2,4,5-T (table 9.3) show that a rapid initial defoliation was almost always followed by rapid recovery. When initial defoliation occurred more slowly, however, the ultimate effect was usually better.

TABLE 9.3.--The percentage defoliation of guava at intervals after treatment with 2,4-D:2,4,5-T applied at 6 lb. per 100 gal. as a wetting spray with a portable compressed air sprayer

Treatment date	Defoliation, time after treatment[1]			
	2 wk.	1 mo.	6 mo.	1 yr.
	- - - - - - - - - Percent - - - - - - - - -			
1963				
Oct. 22	63	69	53	15
Nov. 19	39	54	46	19
Dec. 2	26	75	27	15
Dec. 16	25	65	30	31
1964				
Jan. 3	51	93 a b	35	20
Jan. 13	30	95 a b	47	15
Feb. 3	59	98 a b	36	15
Feb. 17	78 a b	97 a b	38	15
Mar. 2	74 a b	97 a b	22	11
Mar. 17	83 a	99 a	17	9
Apr. 1	66	90 b	18	9
Apr. 13	69	95 a b	40	21
May 4	42	90 b	72 a b	56
May 18	36	75	39	19
June 1	40	77	70 a b	45 a
June 15	25	48	34	16
June 29	36	63	78 a	64 a
July 13	31	46	57 b	43 b
Aug. 3	66	61	55 b	36
Aug. 17	74 a b	77	39	37
Sept. 14	60	67	68 a b	48 a b
Oct. 6	24	67	56 b	28
Oct. 19	26	63	70 a b	43 b
Nov. 2	31	72	59 b	43 b

[1] Any two means having one or more letters in common are not significantly different. Any two means not having letters in common are significantly different at the 5-percent level. Significance is shown only for the high defoliation percentages to show clearly that the defoliation pattern is dependent on season of treatment.

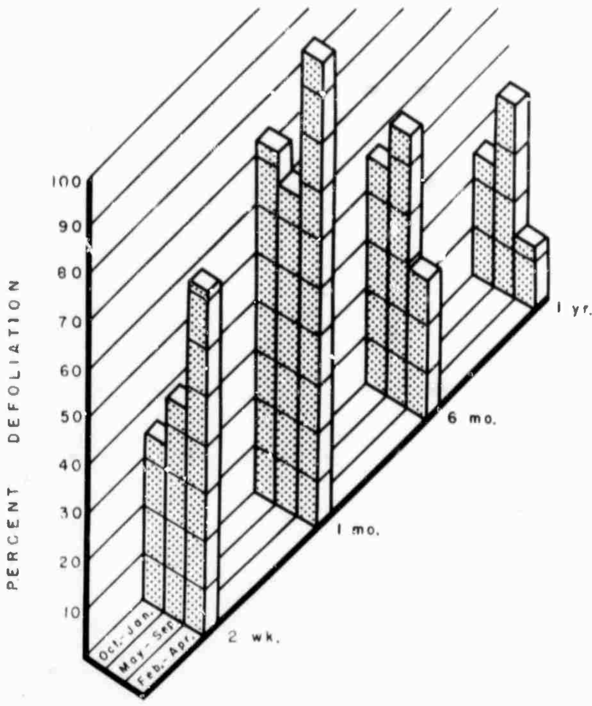

Figure 9.1.--The interrelationship between seasons of herbicide application and defoliation of guava. Data for the three periods are averages of all treatments during a period.

The interaction of initial and ultimate defoliation with seasons of application is shown graphically in figure 9.1. The mean defoliation resulting from treatments made during the periods of February-April, May-September, and October-January show that there are three distinctly different defoliation patterns. Treatments applied during the February-April period resulted in a high initial defoliation but the plants recovered rapidly between 1 and 6 mo. after treatment. Additional recovery occurred between the 6-mo. and 1-yr. observations, so that the ultimate effect was negligible. Treatments applied during the May-September period caused the lowest initial defoliation, but gave the highest ultimate defoliation. The effects of the October-January treatments were intermediate between the other two.

Defoliation patterns can be associated with rainfall and the rainfall can in turn be associated with the growth pattern of guava (8). Rainfall data are given in table 9.4. A comparison of table 9.4 with figure 9.1 shows that high initial defoliation was associated with a period of low rainfall and the highest ultimate defoliation was associated with the period of highest rainfall. The ultimate percentage of defoliation was correlated with rainfall during the 3-wk. period preceding treatment ($r = 0.70$). Since $r \times 100$ is roughly indicative of the amount of change in defoliation that is attributable to rainfall, the correlation coefficient tells us that only about 50 percent of the increased defoliation was due to increased rainfall. The stage of growth at which guava was treated is also an important factor.

Flowering and fruiting of guava occur during the dry season, principally in February and March, but some flowering may occur as late as June. Terminal twig elongation and new leaf development occur during the first part of the rainy season, usually stopping by midsummer. Thus, the period of maximum susceptibility to 2,4-D:2,4,5-T is coincident with a period of high rainfall and maximum foliar development. Defoliation is less dependent on

TABLE 9.4.--Monthly rainfall at Mayaguez, Puerto Rico, during the period covered by this study and the longterm monthly rainfall

Month	Year	Rainfall during study period		Rainfall, long term means	
		Monthly mean[1]	Mean for period[2]	Monthly[3]	Period
		- - - - - - - Inches - - - - - - - -			
Oct.	1963	5.45		8.50	
Nov.	1963	6.68	3.78	5.63	4.66
Dec.	1963	2.24		2.60	
Jan.	1964	.76		1.90	
Feb.	1964	1.63		1.64	
Mar.	1964	.49	3.44	3.50	3.27
Apr.	1964	11.62		4.68	
May	1964	3.26		8.45	
June	1964	9.33		8.78	
July	1964	7.26	8.72	9.60	9.60
Aug.	1964	8.38		10.08	
Sept.	1964	6.63		11.07	
Oct.	1964	10.29			
Nov.	1964	1.24			
Dec.	1964	.46			

[1] Data taken from Mayaguez Station through April 1964; subsequent data taken from rain gage on the study site.
[2] The periods correspond to those used in figure 9.1.
[3] All data taken from the Mayaguez Station.

TABLE 9.5.--Seasonal response of guava to 2,4-D:2,4,5-T compared with the seasonal response to dicamba and picloram. Concentration was 6 lb. per 100 gal. for all herbicides

Treatment period	Time after treatment[1]	Defoliation after treatment with--		
		2,4-D:2,4,5-T	Dicamba	Picloram
		- - - - - - Percent - - - - - - -		
Feb. to April	2 wk.	72	79	86
	1 mo.	96	89	95
	6 mo.	29	69	89
	1 yr.	13	50	81
May to Sept.	2 wk.	46	18	24
	1 mo.	67	23	36
	6 mo.	57	30	75
	1 yr.	40	25	95
Oct. to Jan.	2 wk.	35	24	42
	1 mo.	73	63	71
	6 mo.	47	84	95
	1 yr.	25	75	95

[1] There were from one to six treatments within a period for dicamba and picloram.

rainfall during the later part of the rainy season when there are few, if any, new leaves. Defoliation percentages resulting from treatments on October 19 and November 2, 1964, were not so high as those resulting from treatments earlier in the rainy season, even though there were 10.29 in. of rainfall in October 1964.

The initial reaction of guava to dicamba and picloram was generally the same as for 2,4-D:2,4,5-T (table 9.5). The highest initial defoliation was obtained during the February-April period, but recovery was also greatest from treatments made during that period. The amount of recovery was not so great for dicamba and picloram as it was for 2,4-D:2,4,5-T. In contrast to 2,4-D:2,4,5-T, the period of greatest susceptibility to dicamba and picloram (based on defoliation 1 yr. after treatment) was October to January. During this period initial defoliation percentages were in the intermediate ranges. Thus, it seems that the pattern of response is approximately the same for the three herbicides insofar as initial defoliation is concerned. The period of maximum susceptibility occurred later in the season for dicamba. Maximum susceptibility of guava to picloram occurred during a longer period than for either of the other two herbicides tested.

The pattern of seasonal susceptibility of guava was found to be essentially the same as that for woody species growing in temperate zones. Guava is most susceptible to phenoxy herbicides when treatments are made at the end of a period of active terminal growth. In addition, the period of maximum susceptibility of guava coincided with the period when there was adequate soil moisture for growth. As was the case with winged elm and yaupon, guava was susceptible to picloram over a longer period of time than when 2,4-D:2,4,5-T was used as the herbicide.

It is reasonable to assume that other tropical species growing in an area that has seasonal rainfall would react similarly to guava. Phenoxy herbicides are known to be translocated with photosynthate. The direction of carbohydrate flow is upward in the plant during periods when new leaves are being developed and terminal elongation is taking place. Since the phenoxy herbicides are translocated with the carbohydrates, the herbicide would be concentrated in the new leaves and in the new terminal growth and consequently, a high initial defoliation would be expected. Much of the herbicide would be lost when the leaves dropped. After the leaves have reached full size and terminal growth has stopped, however, the direction of carbohydrate flow is toward the base of the plants. Now the herbicide would be translocated away from the newly developing leaves and terminal twigs into the stems and roots. The net effect would be a lower concentration of herbicides in the leaves and terminal twigs and a correspondingly greater concentration in the stem and root. Rapid defoliation would not be expected. Subsequent redistribution of herbicide would ultimately lead to a higher percentage of defoliation and a greater number of plants killed.

The reasons for the longer periods of susceptibility of woody plants to picloram than to phenoxy herbicides are unclear. Studies have shown that picloram is absorbed more rapidly and in greater quantities than is 2,4,5-T (2). It is also known that picloram is translocated more readily than 2,4,5-T, particularly toward the basal portions of the plant (6). Picloram appears to be both phloem and xylem-mobile whereas 2,4,5-T is only phloem-mobile. Thus, the translocation of phenoxy herbicides toward the basal portions of the plant would occur only when mass flow of the photosynthate was moving in that direction. Picloram, on the other hand, would be translocated to the basal portions of the plant regardless of the direction of photosynthate flow. The bidirectional flow of picloram results in slow, but progressively greater, defoliation and excellent suppression of lateral and basal buds. The dependence of 2,4,5-T on transport with photosynthate restricts the period during which it can be most effective. In addition, some of the picloram applied as a foliage spray will reach the soil. Picloram is more persistent in soil than is 2,4,5-T and thus would be available to the plant by soil absorption.

The concept of seasonal susceptibility probably does not extend to a tropical rain forest where neither temperature nor moisture limit plant growth during any season of the year. Radial growth and the fall and replacement of leaves occur at a fairly uniform rate throughout the year (7). The absence of periods during which the trees have a relatively greater growth activity prevents the timing of treatment with a phenoxy herbicide to coincide with the downward flow of photosynthate. Thus, it is reasonable to expect that the degree of susceptibility of rain forest species would not vary greatly throughout a year. Additional research would be needed to substantiate the expected lack of seasonal susceptibility of rain forest species.

The data presented in this chapter showed that guava growing in a tropical climate characterized by seasonal rainfall exhibits a seasonal susceptibility similar to that of woody species growing in temperate zones. Other woody species growing in an environment similar to that of guava could be expected to react in a similar manner. Marked seasonal variations in susceptibility would not be expected in a tropical rain forest.

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CHAPTER 10

THE EFFECT OF DEFOLIATION ON HORIZONTAL AND VERTICAL OBSCURATION BY VEGETATION

The ARPA defoliation project was initiated because of the belief that defoliation of a tropical forest would improve both horizontal and vertical visibility. Some work had been done on visibility in a horizontal plane in a number of forest types, but visibility had never been related to defoliation. It was important, therefore, to study the relationship between visibility and the progressive defoliation caused by chemical herbicides.

This report is limited to a discussion of the effects of vegetation on visibility as it relates to military requirements. A review of the literature shows that the first work was done by the U.S. Army Quartermaster Research and Development Command at the request of the General Staff (10). That study emphasized the continuous variability of vegetation and the consequent difficulty of classifying vegetation for the purpose of relating it to visibility. Drummond and Lackey used Kuchler's vegetation classification (11), but recognized its limitations. Drummond and Lackey proposed the term "continuous visibility," defining it as, "...the greatest distance to which a quiet, erect, stationary man can be kept in constant view as the observer goes away from him ...." Their standard visibility object was a green cylinder 6 feet in height and 1.5 feet in diameter.

The work of Drummond and Lackey in the deciduous and coniferous forests of the United States was extended by Anstey (1) to a tropical deciduous forest in Panama. The difference between temperate and tropical forests was recognized by Anstey when he said that, "... Most of the obstruction to visibility in a tropical deciduous forest is due to undergrowth, vines, epiphytes, and exposed buttress roots or fallen trees...." Anstey's visibility target was a man dressed in the standard U.S. Army utility uniform including tropical boots and a standard field cap. In one test the observer was positioned and asked to search for a moving visibility target. In the second test, the target was stationary and had to be spotted by the moving observer. The moving target could always be spotted at a greater distance than could the stationary target. Anstey also noted that a professional hunter with many years experience in a similar environment was able to locate the stationary target at a greater distance than could the regular observer.

In 1963 the U.S. Army Corps of Engineers also started to work on the problem of visibility (14). They used a moving target essentially similar to the method described by Anstey (1).

In 1964 the Natick Laboratories brought together the results of field observations from eight widely scattered vegetation types, ranging from tropical forests in Panama to the subarctic coniferous forests of Canada (2). This publication marked a change in methodology for the Natick Laboratories. While they had formerly used a green cylinder or a man in a green uniform, they now used a white disc and proposed its use as a standard for measuring visibility in vegetation. The recommended disc was 30 cm. in diameter and painted dull white.

The use of a white disc in preference to a man or cylinder garbed in green represents a basic change in thinking about the many problems associated with a concept so broadly definable as is visibility. The use of a green-garbed target incorporates the element of camouflage and introduces the probability of prior experience being a distinct advantage for target perception. An experienced hunter accustomed to locating game in a given environment would be expected to locate a camouflaged target sooner than someone who was inexperienced in that environment. A white disc, on the other hand, contrasts with the green foliage and can be seen equally well by the experienced and the inexperienced. Thus, the white disc would be more a measure of the degree of obscuration of vegetation, whereas the recognition of a camouflaged target would be more a matter of detection or discernment of a target that blends in with the environment.

In 1964 the U.S. Army Tropic Test Center published the first in a series of papers on "Jungle Vision" (4). The objective of their first study was to determine the detectability of uniformed human targets in a semideciduous tropical forest during the dry season. They established a range of visual detection thresholds from 45 to 75 ft., depending on the particular site in the semideciduous forest. A detection threshold was defined as the distance at which 50 percent of the targets were detected.

The second report by the Tropic Test Center (5) also had the detection of uniformed human targets as its objective and the same procedures were used. The second test extended the work from a semideciduous forest during the dry season to an evergreen rain forest during the wet season. The detection thresholds for the two forests did not differ significantly, but target detection between 65 and 100 ft. was much more difficult in the evergreen forest than in the semideciduous forest. Dobbins and Gast also found a statistically significant relationship between detection thresholds and illumination levels. The range of illumination in the rain forest was from 4 to 17 ft.-c.

The third jungle vision report (6) was concerned with determining whether there were sufficient changes in rain forest vegetation during the dry season to enable soldiers to detect uniformed human targets more readily than during the wet season. The same methodology was used as in their previous work. The authors concluded that there were no significant differences in target detectability between the two seasons in spite of higher levels of illumination, observable vegetation changes, and a severe dry season.

The next report by the Tropic Test Center (7) continued the work with camouflaged targets. In this test nonmagnifying yellow lenses were tested to determine if they would increase the probability of target detection. The tests were made in three sites of an evergreen rain forest during the dry season and compared with earlier tests at the same sites. Target detectability was decreased rather than increased by using the yellow lenses.

Dobbins and Kindick (8) next tested yellow, red, and dichroic nonmagnifying lenses in two sites of a semideciduous tropical forest during the wet season. None of the lenses improved target detectability as measured by 50 percent detection thresholds.

The latest publication by the Tropic Test Center on problems associated with visibility (9) had as its objectives a comparison of human targets with several standard visibility objects, and an evaluation of the effectiveness of one U.S. Army camouflage pattern in reducing visual detection. The work was done on two sites in an evergreen forest. The targets that were compared were (1) human in an olive drab uniform, (2) olive drab silhouette (in the shape of a man), (3) camouflaged silhouette, (4) olive drab cylinder 6 by 2.5 ft., (5) a single white disc 30 cm. in diameter and 1.55 m. above the ground, and (6) a double white disc, the lower one 49 cm. in diameter and 0.4 m. above the ground, the upper one 30 cm. in diameter and 2 m. above the ground. The double white disc was most easily detectable, followed by the three olive drab targets that were equally detectable, the single disc, and the camouflaged silhouette.

The lack of comparable detectability between the olive drab targets and the white discs is to be expected simply on the basis of the differences between a color that blends with the vegetation and one that contrasts with the vegetation. The fact that the double disc provided the highest detectability and the single disc provided the next to the lowest detectability is doubtless a function of size of the detectable objects. Total area of the double disc was 2,593 sq. cm., whereas the total area of the single, 30-cm. disc was only 707 sq. cm. Thus, not only was the blending vs. contrasting color important, but also the size of the target to be detected.

The literature that has been reviewed shows that the specific objective to be studied within the general concept of "visibility" must be closely defined if there is to be a comparison of the work of different individuals in different areas. Moreover, the techniques for a specific objective must be similar or it will never be possible to assess comparability.

Visibility may be defined as the degree or extent to which something is visible (recognizable), or as a measure of the ability of radiant energy to evoke a visual sensation. The first definition refers principally to visual perception that may be influenced by such atmospheric conditions as cloudiness, dust, rain, and so on. The second definition refers to the influence of radiant energy in the visible portion of the spectrum on visual perception. Neither definition fits the mental concept of "visibility" in vegetation of varying stature and density.

Even when the term "visibility" is confined within a vegetation frame of reference, it still evokes different inferences in the minds of different individuals. Someone interested in the detection of a camouflaged target will certainly think in different terms than one who is interested in the detection of a contrasting target. Both approaches have merit and information about them should be developed. But there should be a terminology that prohibits two individuals with different objectives from using the same word to describe what they are testing.

A number of terms have been used in the research that has been done on visibility in different vegetation types. It should be borne in mind, however, that all the work has been done on visibility in a horizontal plane. There has not been an attempt to assess visibility in terms of what an observer on the ground can see when looking toward the sky. Neither has there been an attempt to assess the visibility of an object on the ground by an aerial observer.

The terms "continuous visibility" (10) and "detection threshold" (4) have been defined. The Tropic Test Center also used the term "detection time," which is the time needed to detect a target at a given distance within a 180° field of view. Visibility and horizontal visibility have been used generically without precise definition by everyone who has been concerned with the problem.

A new term, "obscuration," was suggested by the Waterways Experiment Station (15) and recommended by the authors in their 1964 Annual Report. The new term differs from previous terms in that it expresses quantitatively how much of a target is obscured by vegetation. Obscuration thus becomes a measure of the amount of obscuring vegetation between observer and target. Obscuration, for both horizontal and vertical planes, will be used in preference to visibility in this report.

The objectives of this study were to determine the effect of defoliation on horizontal and vertical obscuration, and to compwre two systems for measuring horizontal obscuration and two methods for measuring vertical obscuration.

Materials and Methods

The research site was located in the Luquillo National Forest on the northwest slope of the Luquillo mountains. Elevation was 540 m., topography steep. The forest was classified as lower montane rain forest (3) and occurred in the tabonuco type (16). The immaturity of the forest was indicated by the absence of large tabonuco and the scarcity of small tabonuco, which come in under the shade of an established canopy. The general level of the canopy was about 60 ft. Many small trees formed an understory layer 10 to 50 ft. high. Tree density was 2.2 per 100 sq. ft. Tschirley and Dowler (13) gave a detailed taxonomic and physical description of the area.

Nine, 60- by 80-ft. plots were treated with a pelleted formulation of picloram on February 9, 1965. Rates of picloram were used that previous experience indicated would provide a defoliation gradient from 0 to 100 percent. The herbicide was applied with a cyclone hand seeder.

Two methods were tested for the quantitative measurement of horizontal obscuration. The methods were similar and used the same control points so that direct comparisons could be made on the basis of accuracy, time required for measurement, and the correlation with the percentage of defoliation. A plot diagram showing the essential features for measurement of horizontal obscuration is shown in figure 10.1. The observation point for both methods was the center of the plot, marked by a length of 1-in. pipe. Target locations were

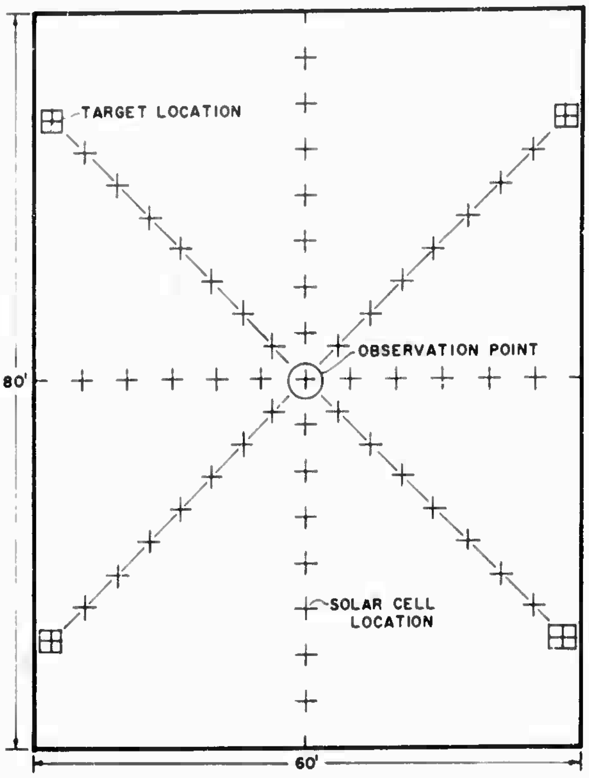


Figure 10.1.--Plot diagram showing the observation point and target locations for measuring horizontal obscuration.

at the ends of 40-ft. radii located 45° from the long axis of the plots.

The dot-count method was suggested by Waterways Experiment Station. The target was composed of three, 30-cm. discs fastened to a staff. The centers of the discs were 0.4, 1.2, and 1.95 m. above the ground. There were 25 brightly colored thumbtacks randomly located on each disc. Each disc was fastened to the staff in such a way that it was free to spin. In practice the target was placed in the desired location and each disc was given a spin so that location of the dots was, theoretically, never the same. The observer counted the number of visible dots on each disc through a monocular mounted on the pipe in the center of the plot. The monocular was about 5 ft. above the ground. Data were recorded on prepared sheets so that all essential information was included and the possibility of error was reduced.

The second method used for quantitatively measuring horizontal obscuration was called the stereo-square method. The obscuration target was composed of three, 30- by 30-cm. units fastened to a staff. The centers of the squares were 0.4, 1.2, and 1.95 m. above the ground--the same as for the dot-count method. Each of the square units was subdivided into 25 alternating, black and white, 6 by 6 cm. squares. In practice the target was placed in the desired location and photos were taken from the plot center with a 4 by 5 Graflex. Two photos were taken (4 in. horizontal camera displacement) so that the number of visible squares could be counted stereoscopically. When more than half of a square could be seen it was counted as visible; when less than half could be seen the square was not counted. The observation point and target locations were the same as for the dot-count method (fig. 10.1).

One method of assessing vertical obscuration made use of the principle and equipment devised by Odum (12). This method is based on an increasing attenuation of light reaching the forest floor by an increasing density of the forest canopy. The ratio of light above the canopy to that at the forest floor is called optical density (OD) and is expressed as,

$$OD = Log_{10} \frac{L}{L'}$$

where L = light above the forest canopy, and L' = light at the forest floor.

Solar cells manufactured by International Rectifiers (Model B2M) were used for the measurement of OD. The solar cells have a 180^{o} angle of acceptance and are sensitive in the visible and infra-red portions of the spectrum.

One of the solar cells was raised above the forest canopy in a central location. The second solar cell, measuring the incidence of light at the forest floor, was held about 2 feet above the ground at 61 locations on each plot. The arrangement of locations is shown in figure 10.1. Stakes were placed at 5 foot intervals on each of the eight radii so that subsequent OD measurements could be made from the same location.

The second method for measuring vertical obscuration made use of photographic techniques. Photos were taken from plot centers with a camera equipped with an 8 mm. "fisheye" lens. The "fisheye" has a 180^{o} angle of acceptance which results in a circular photo. Photos were taken on black and white panchromatic film. Exposures were made on the basis of illumination from the sky with a Pentax 1/21 exposure meter, which has a 1^{o} angle of acceptance. After developing the 35 mm. panchromatic film, negatives were enlarged to 170 mm. in diameter and transposed as positives to a high-contrast kodalith.

The final positives, on which vegetation was opaque and unobstructed sky was transparent, were analyzed visually and by percentage of light transmission. Obscuration was determined within an included angle of 140^{o}. Visual examination of the positives was made by using an acetate overlay divided into three sectors of equal area for each of eight arcs. The percentage obscuration was estimated for each sector, summed, and divided by 24 to give the percentage obscuration for each photo.

The equipment used for measuring vertical obscuration by the percentage of light transmission included (1) a light table, (2) a black mask to screen out any light except that coming through a 140 mm. diameter circle that represented an included angle of 140^{o}, (3) a photo tube, (4) a photo multiplier with an indicating dial, (5) a voltage regulator, and (6) a rheostat. The photomultiplier, having an integral voltage regulator, was hooked directly to a 110 v. line. A voltage regulator and a rheostat were placed between the 110 v. line and the light table. The voltage regulator was necessary to provide a light source of constant intensity. The rheostat was used to vary light intensity during zeroing of the photomultiplier.

The photomultiplier and light table were warmed up for about 30 min. before any measurements were made. A transparent sheet of kodalith was then placed on the light table and covered with the black mask so that the only light reaching the phototube came from a circle representing a 140^{o} included angle. By varying light intensity on the light table, and adjusting the internal compensating mechanism of the photomultiplier, the instrument was calibrated for 100 percent transmission. A sheet of opaque paper was then put on the light table and the instrument was adjusted for zero transmission. The same procedure was repeated one or more times until the instrument gave constant readings of zero and 100 percent. Canopy positives were then placed on the light table, masked for a 140^{o} included angle, and the percentage of light transmission read directly from the indicating dial on the photomultiplier.

Results and Discussion

Horizontal Obscuration

Comparison of dot-count and stereo-square-count methods.--The comparison of dot-count and stereo-square-count methods was made by correlation and regression analyses. Analyses were made for each of the three levels and for all levels combined. Four readings for each of 10 plots on 8 calendar dates made a total of 320 observations for each analysis.

The correlation coefficients for individual levels were low, ranging from 0.024 through 0.21 to 0.32 for the top, middle, and bottom levels, respectively. When all levels were combined, however, the correlation coefficient was 0.80.

There are several reasons for the poor correlations for individual levels in the two methods. The area of the 30-cm. disc used for the dot-count was 70.5 sq. cm., but the combined area of the 25 thumbtack heads was only about 24 sq. cm. The area of the 30-cm. square used in the stereo-square-count method was 900 sq. cm. and all of it was used for assessing visibility. In addition, the random location of tacks might lead to their being grouped in a small target area. In that case a single leaf near the observer could obscure all or many of the tacks and lead to a high obscuration value. Percentage obscuration for the dot-count was, in fact, always higher than for the stereo-square-count. And as defoliation increased (fewer obscuring leaves) the spread between obscuration percentages for the two methods increased. Thus, it seems clear that a single leaf can have a greater influence on the results obtained with the dot-count method than with the stereo-square method. The magnitude of the effect of a single leaf would be reduced if there were a regular grid pattern of tack location rather than a random pattern that permits grouping of tacks.

Another reason for poor correlation between individual levels of the two methods is leaf movement caused by wind. Although the time required to count the 25 dots was not measured, 5 sec. probably represents an average time. Leaf movement during the time needed for counting dots would alternately cover and uncover dots, making an accurate count extremely difficult. The photographic record obtained from the stereo-square method is obtained in a fraction of a second--photos were never taken at a shutter speed slower than 1/25 sec. The only human bias involved in the stereo-square-count method was determining whether more or less than half of a square was obscured. Granting that bias, the reproducibility of results would still be greater for the stereo-square-count than for the dot-count.

Much less time was required for obtaining results with the dot-count than with the stereo-square method. A two-man team could make the dot-count on 10 plots in 2 hr. Three hours were needed for a three-man team to take stereo-pair photographs on the same 10 plots. The film then had to be developed and printed, and counts made from the finished prints. Assuming 1 man-hour for developing and printing and 0.75 man-hour for counting squares, 10.75 man-hours were needed to obtain obscuration data on 10 plots. Only 4 man-hours were required for the dot-count.

The stereo-square method is considered to provide more reliable data than does the dot-count. In addition, the stereo-square method has the advantage of a photographic record that gives someone unfamiliar with the area an appreciation of the vegetational structure that is not possible with the dot-count. The dot-count is clearly superior from the standpoint of time required to obtain data, however.

Effect of defoliation on horizontal obscuration.--The effect of defoliation on obscuration was actually greater than expected. Obscuration data for both methods were analyzed separately. The mean obscuration calculated from the four target locations on a plot were plotted against percentage defoliation for the same plot. Linear regressions for both methods are shown in figure 10.2. A higher correlation coefficient was obtained with the stereo-square method (-0.67) than with the dot-count (-0.61).

Previous discussion has shown that the stereo-square method provides more reliable data than does the dot-count. Consequently, future discussion of the relationship between defoliation and horizontal obscuration will be based only on the stereo-square method.

The relationship between defoliation and horizontal obscuration is influenced markedly by the amount of obscuring foliage present before treatment. If a target happens to be located so that only a small portion, or none of it, can be seen before treatment, defoliation has a striking effect on the number of squares that can be seen. On the contrary, a target visible before treatment is still visible after treatment, so the effect of defoliation on obscuration is nil. The two situations are apparent in the series of photos in figures 10.3 to 10.6, inclusive. The pictures represent a chronologic sequence for each of 4 radii on a plot. Obviously, more than one target location is necessary to obtain a mean obscuration value that is correlated with defoliation. No work has been done to determine the number of target locations, beyond which there would be no improvement of correlation between obscuration and defoliation.

An analysis of the relationship between the three target levels and the degree of defoliation is interesting. Correlation coefficients for the top, center, and bottom levels were -0.69, -0.52, and -0.34, respectively. The lower values for the lower target levels are interpreted to mean that obscuration near the ground is principally a function of stem basal area or of low-growing ground cover that does not enter into the estimated defoliation. Farther above the ground the stems are smaller and there are more leaves. Defoliation of the leaves would naturally result in a higher correlation coefficient.

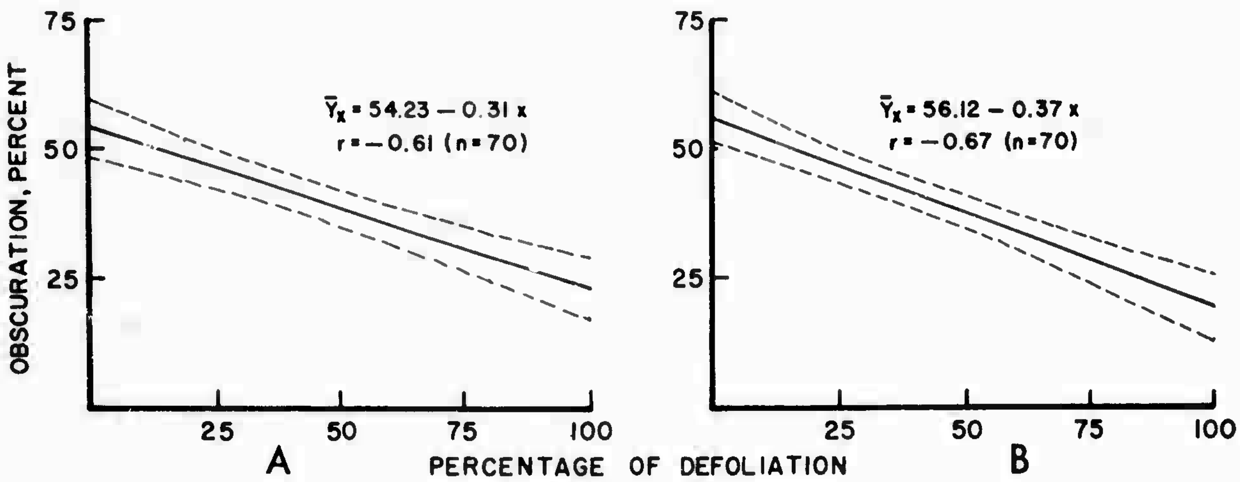


Figure 10.2.--Linear regressions showing the relationship between defoliation and obscuration as determined by dot-count (A) and stereo-square-count (B).

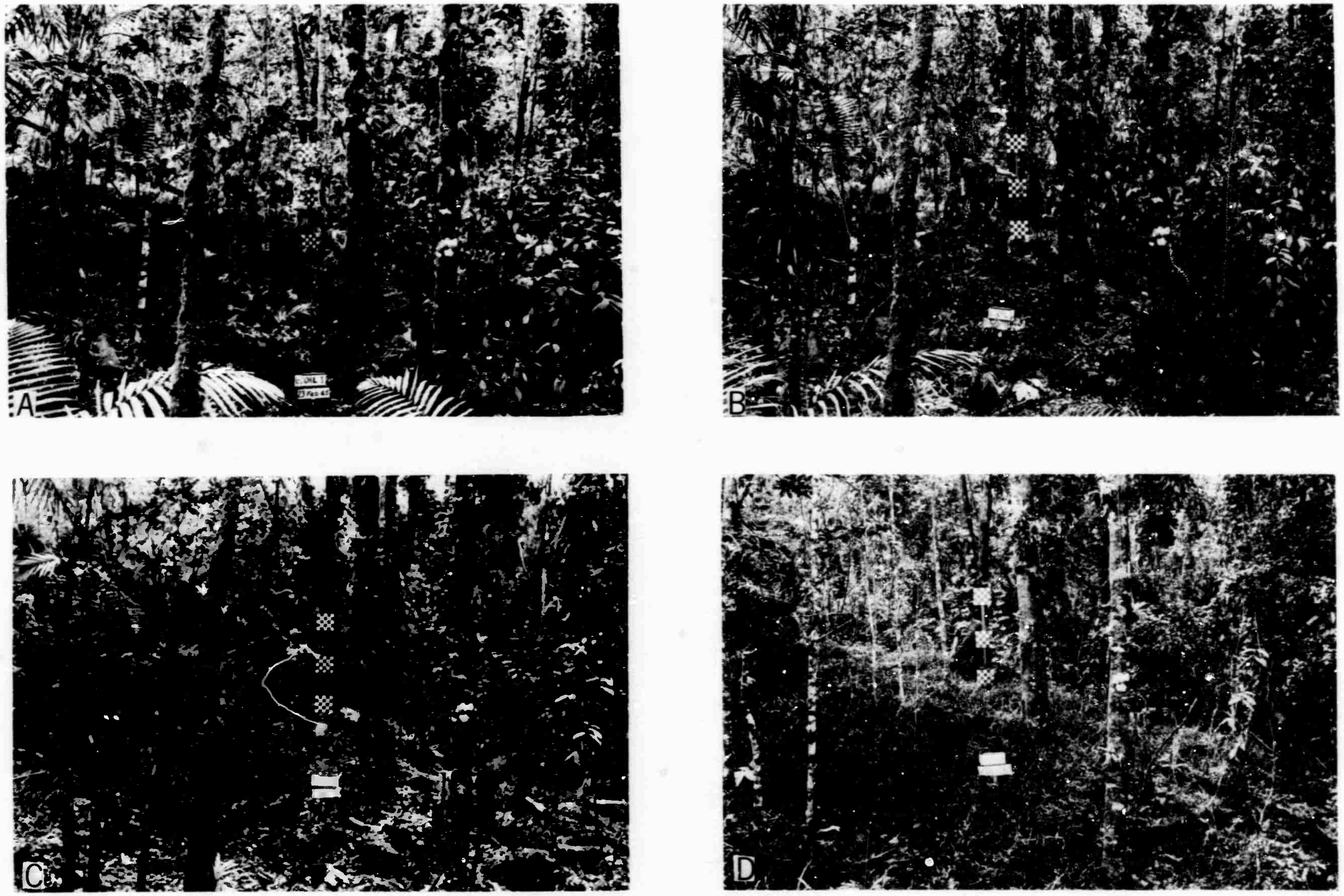


Figure 10.3.--The obscuration of targets on radius 1, 30 feet from the camera lens, and relation of obscuration to defoliation of all woody plants greater than 1 inch d.b.h. The percentages of defoliation were: A, 8; B, 80; C, 90; and D, 99.

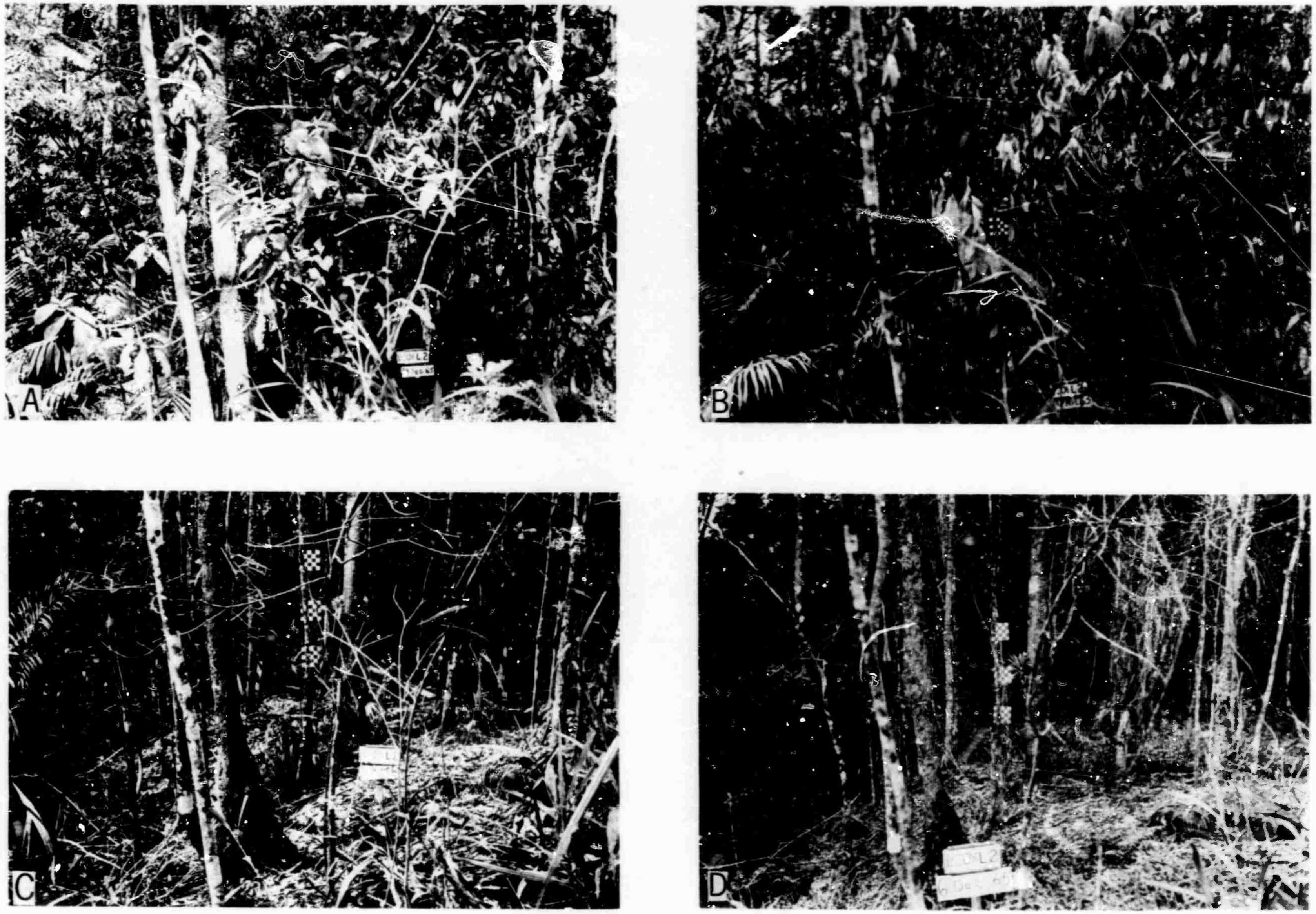


Figure 10.4.--The obscuration of targets on radius 2, 30 feet from the camera lens, and relation of obscuration to defoliation of all woody plants greater than 1 inch d.b.h. The percentages of defoliation were: A, 8; B, 80; C, 90; and D, 99.

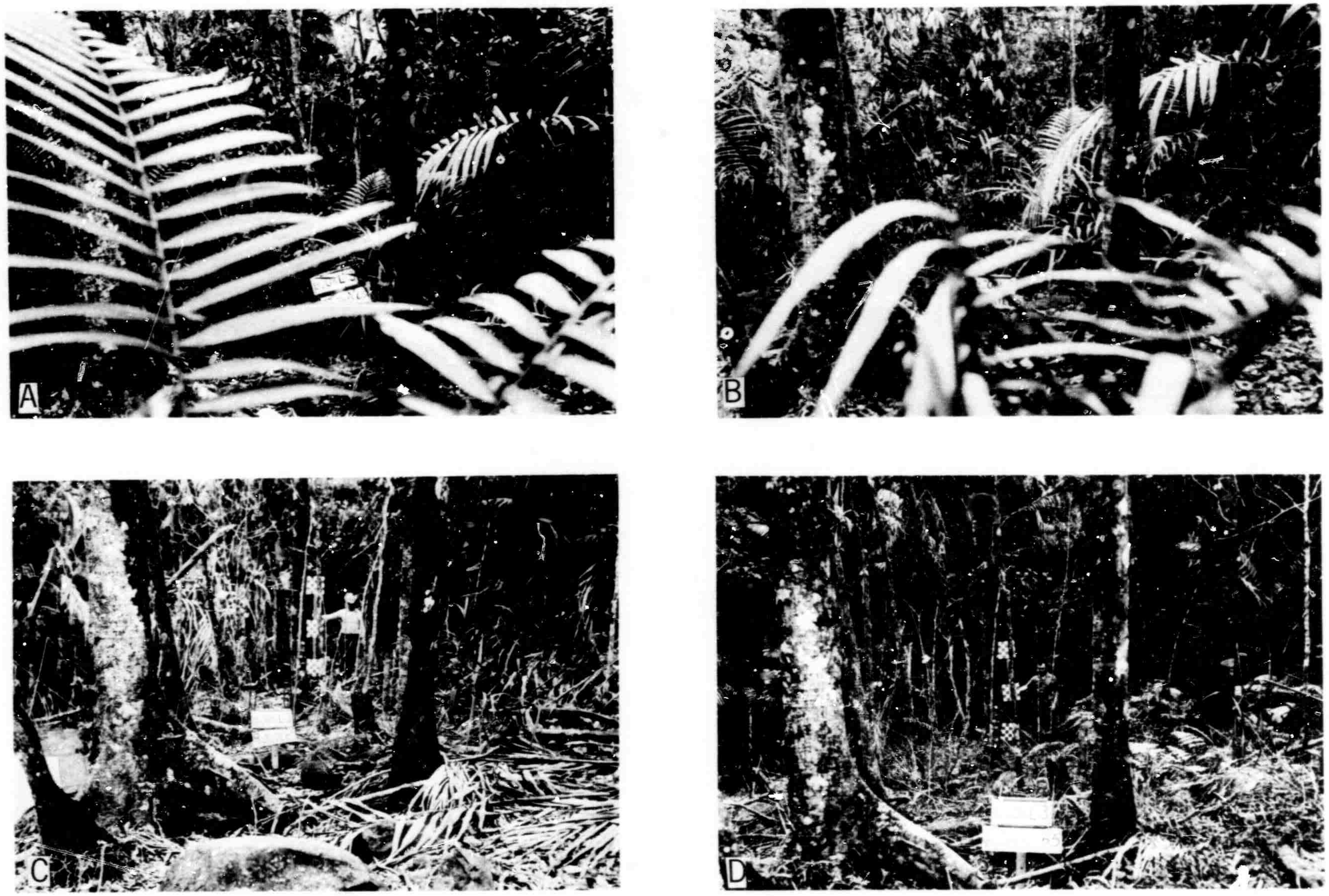


Figure 10.5.--The obscuration of targets on radius 3, 30 feet from the camera lens, and relation of obscuration to defoliation of all woody plants greater than 1 inch d.b.h. The percentages of defoliation were: A, 8; B, 80; C, 90; and D, 99.

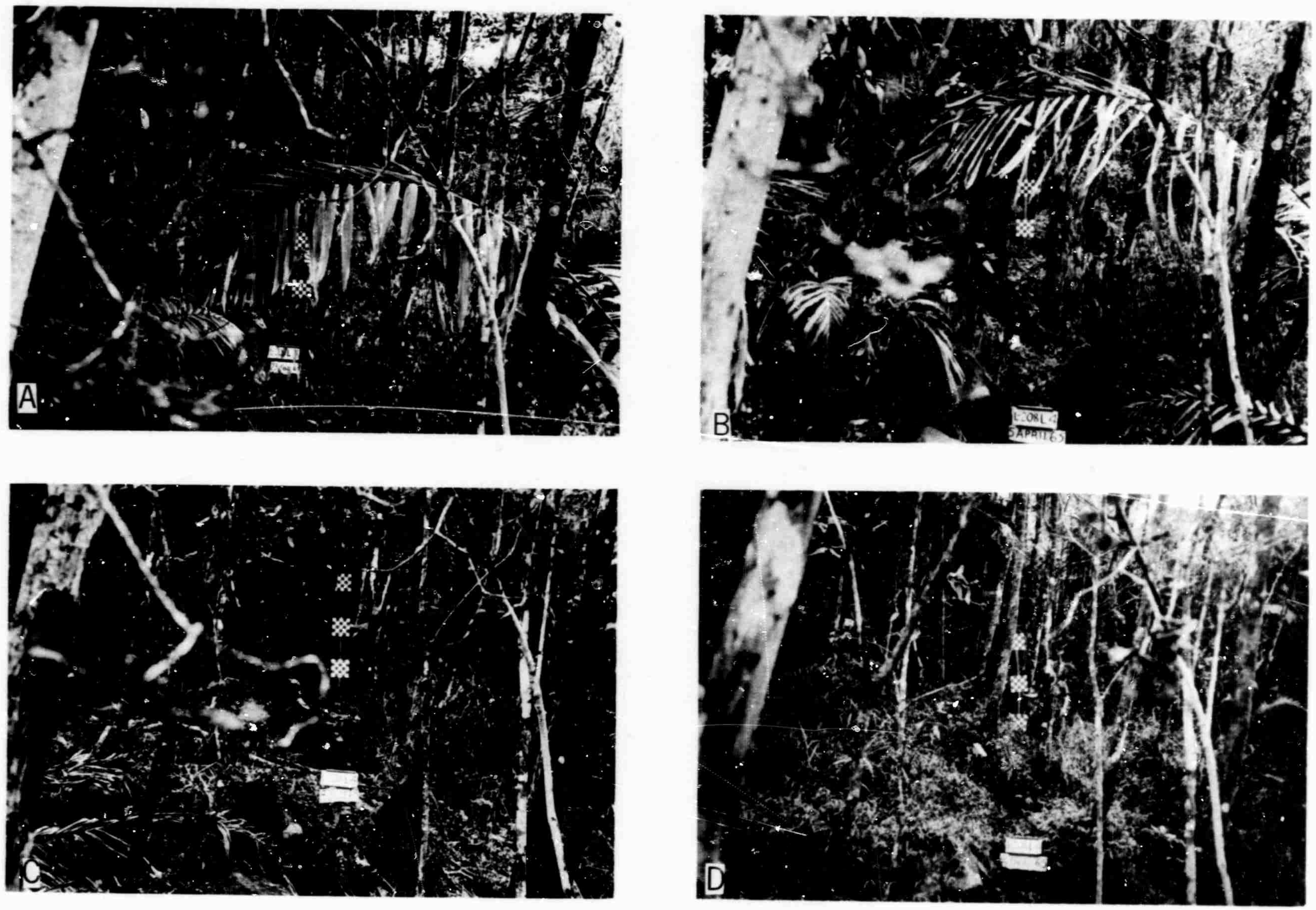


Figure 10.6.--The obscuration of targets on radius 4, 30 feet from the camera lens, and relation of obscuration to defoliation of all woody plants greater than 1 inch d.b.h. The percentages of defoliation were: A, 8; B, 80; C, 90; and D, 99.

Vertical Obscuration

Comparison of canopy photos and optical density.--The comparison of canopy photos and optical density had to be made to provide meaningful data for optical density in terms of its relationship to vertical obscuration. Optical density (OD) is defined as $\log_{10} \frac{L}{L'}$. Thus, the more light that penetrates to the forest floor, the lower is the OD value. Although OD can be related directly to the amount of light penetrating a forest canopy, OD in itself is meaningless in terms of obscuration.

Data were plotted to show the relationship between OD and percentage of obscuration as determined from canopy potographs. Correlation coefficients were calculated for 1, 9, 17, and 25 OD measurements on a plot. The resultant values of r were 0.46, 0.59, 0.63 and 0.63, respectively. Since the value of r did not increase when more than 17 OD measurements per plot were used, about 20 OD measurements can be considered adequate to provide data that correlate well with percentage obscuration measured from a single canopy photo.

The mean OD corresponding to a given percentage obscuration can be determined from linear regression (figure 10.7). The line of regression extends only from 10 to 90 percent obscuration. The regression would not be linear below 10 percent obscuration because the incident light above the forest canopy and at the forest floor would be the same if there were no obscuration. The quotient of the light ratio would be one, and the $\log_{10}$ would be zero. In like manner, the regression would not remain linear for 100 percent obscuration. With no incident light at the forest floor, OD = $\text{Log}_{10} \frac{L}{O} = 0$.

Relationship between vertical obscuration and defoliation.--There is a good relationship between vertical obscuration and defoliation (fig. 10.8). One might expect that, knowing the percentage of obscuration before treatment with herbicides, it would be possible to predict the percentage of defoliation necessary to reduce obscuration to a given level. Such a prediction is not possible from the data obtained in this study, however. Variables that affect the degree of obscuration are (1) the number of stems per unit area, (2) relative density of foliage, (3) height of the vegetation, and (4) basal area of the stems. A predictive equation is not possible unless all variables are taken into consideration.

An example of the variables affecting obscuration is shown by a pair of canopy photos--one taken before treatment, the second three months after treatment (fig. 10.9). Obscuration was extremely high before treatment and most of the obscuration was a result of dense foliage. Three months after treatment, defoliation had revealed enough of the area so that the relative number of stems and their size was evident. One can readily observe that the high stem density at the bottom of the picture caused more obscuration than the low stem density at the top of the picture. Also, the large stem at the top and the third stem to its right were the same distance from the lens, but the larger stem caused much more obscuration. Height of the vegetation is an important variable simply because an oblique line of sight through a forest canopy is longer for taller trees. The line of sight through trees at an angle 45° above horizontal would be 71 ft. for a 50-ft. canopy and 142 ft. for a 100-ft. canopy. Thus, the decreased obscuration resulting from defoliation (fig. 10.8) in this study cannot be extrapolated to other forests. Rough approximations could be made but the approximations would not have the validity of supporting data.

Vertical obscuration from the air to the ground is also influenced by the degree of defoliation. The degree of defoliation is, however, highly dependent on the angle of sight. Targets lying on the ground may be clearly visible when one is directly overhead, invisible when viewed from one oblique angle, and visible when viewed from another oblique angle. An example of decreased air-to-ground obscuration is shown in figure 10.10. An analysis of many aerial photographs indicated that, for this forest, the minimum defoliation that will reduce obscuration to the point where most of the ground is visible is about 50 percent. Even then, the same ground area will be more or less visible depending on the angle and direction from which it is viewed.

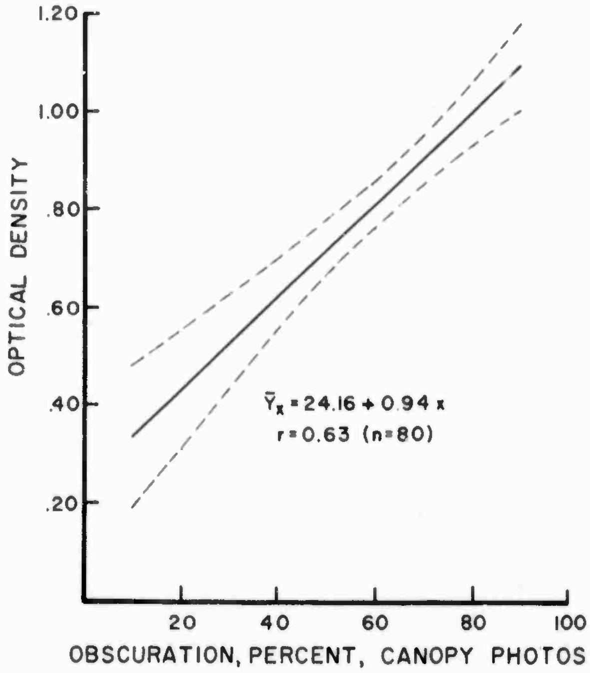


Figure 10.7.--Linear regression and 95 percent confidence intervals for the relationship between obscuration and optical density.

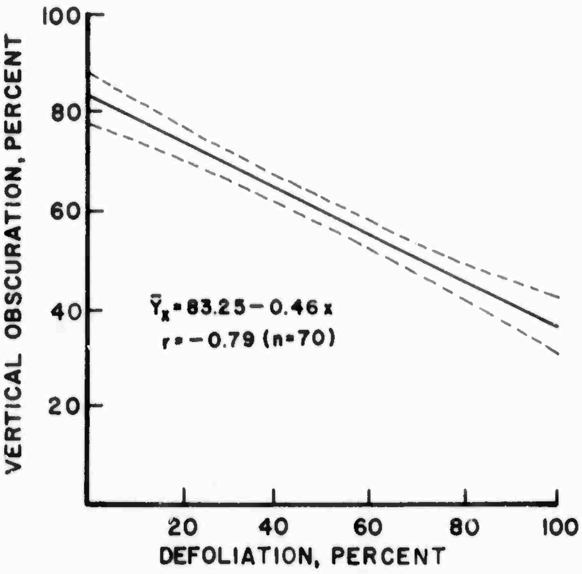
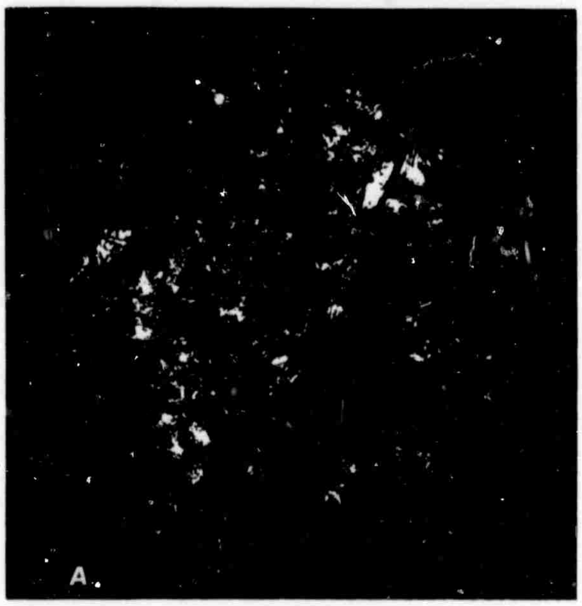


Figure 10.8.--Linear regression and 95 percent confidence intervals for the relationship between vertical obscuration and defoliation.



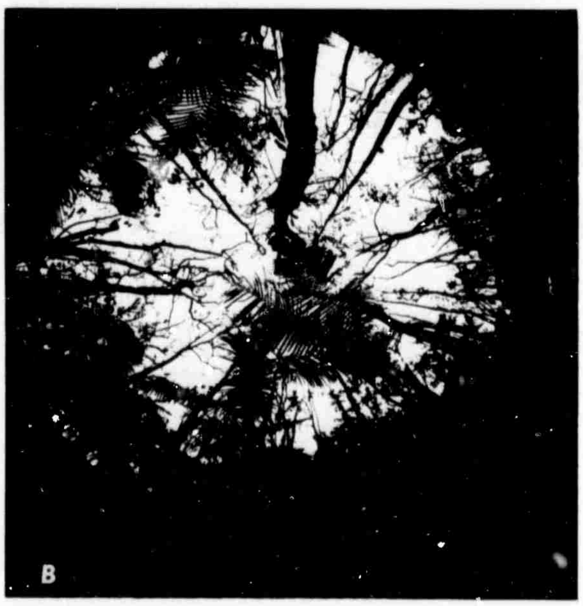


Figure 10.9.--Canopy photos taken with an 8-mm. "fisheye" lens before treatment (A) and 3 mo. after treatment with 6 lb. per acre of picloram (B).

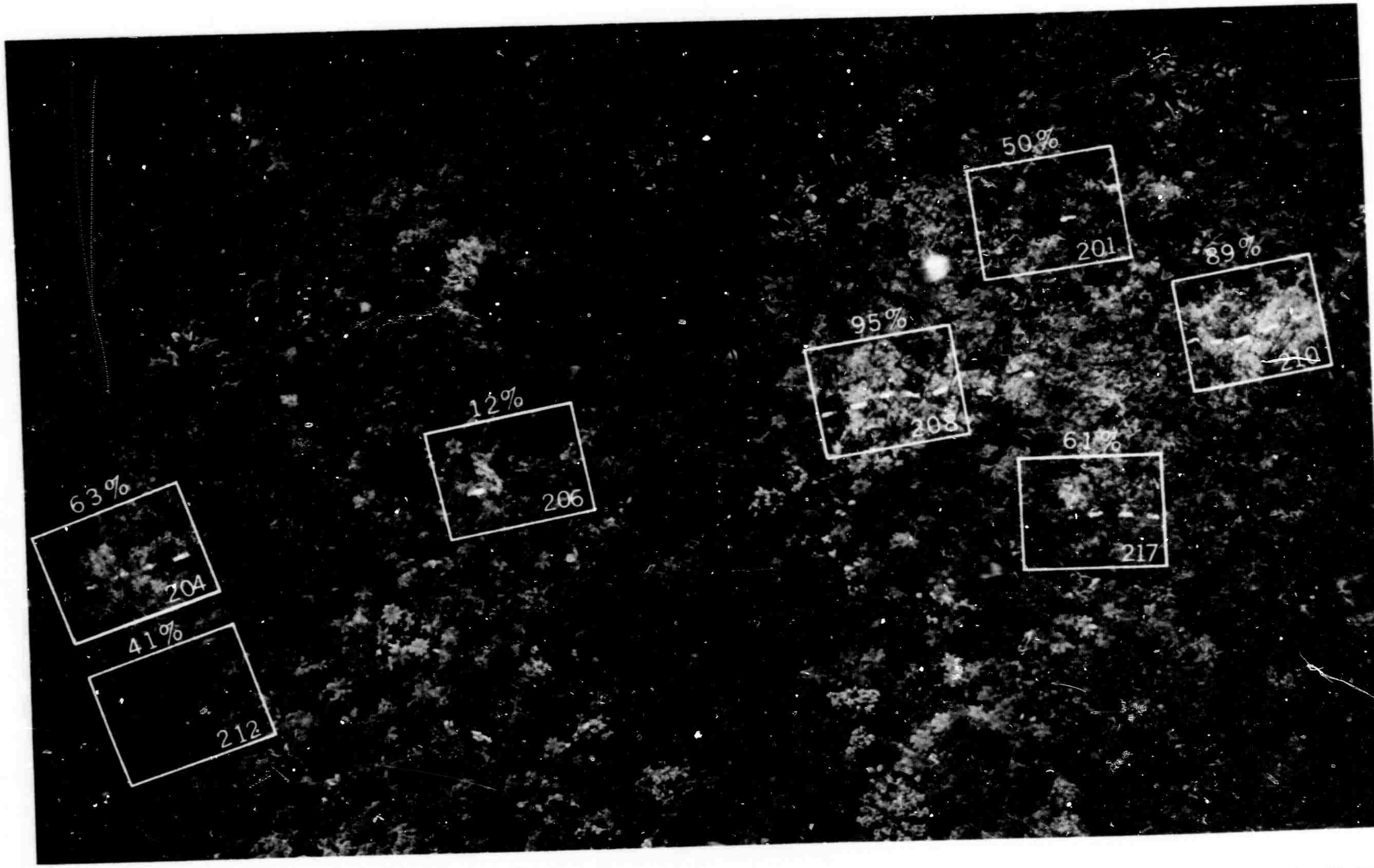


Figure 10.10.--White, 2- by 8-foot targets visible on the ground after defoliation. Percentages of defoliation for the various plots were: 201, 50; 204, 63; 206, 12; 208, 95; 210, 89; 212, 41; and 217, 61.

Summary

The study directed toward assessing the degree of horizontal and vertical obscuration showed that defoliation has a definite, measurable effect on how much of a stationary target can be seen. The relationship between defoliation and obscuration is linear and can be expressed by linear regression. Air-to-ground obscuration is greatly reduced by 50 percent or more defoliation. The degree of obscuration is dependent on the angle and direction of sight, and the height of vegetation.

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CHAPTER 11

HERBICIDE APPLICATION, PENETRATION AND DISTRIBUTION THROUGH FOREST CANOPIES

The engineering phases of the ARPA project involved the fabrication of specialized equipment for herbicide application and a study of factors affecting the penetration and distribution of spray solutions through multistoried forest canopies. The latter objective is intimately associated with herbicidal effectiveness. A herbicidal spray solution that is intercepted by the upper story of vegetation will have no effect on lower stories. The factors affecting spray penetration and spatial distribution include (1) the density of vegetation, (2) mean droplet diameter, (3) evaporation, (4) horizontal air currents resulting in drift away from the target area, and (5) vertical air movement caused by warm, expanding air rising from a soil surface whose temperature is higher than the air.

No herbicide can be effective unless it is delivered to the vegetation to be controlled. The problems associated with herbicide delivery are complex and not amenable to simple solution. In general, the farther the distance from delivery origin to target, the greater is the possibility of misapplication. Spraying with ground equipment, where the delivery origin is close to the target, does not present great problems. But spraying from aircraft, either fixed-wing or helicopter, introduces a complex set of variables whose interactions are seemingly infinite. Thus, the study of spray delivery to the intended target is a vital aspect of the broader concept of herbicidal efficacy.

Equipment Development

Several pieces of specialized equipment were needed for various phases of the overall research effort. This equipment could not be purchased and so had to be fabricated from component parts.

Telescoping-Pole Sprayer

The treatment of large trees for the purpose of herbicidal evaluation was an immediate problem in Puerto Rico. The island is heavily inhabited so areas of sufficient size for aerial treatment were not readily available. Cutover pasture lands containing relatively low-growing woody plants were available, but the invading brush was composed of only a few species. Confining herbicidal evaluation to a few woody species would have been a serious detriment to studying herbicidal effectiveness on a broad taxonomic base. Trees in an established second growth forest were too tall for effective treatment by conventional methods from the ground.

The requirements for a system that could be used to spray individual large trees were: (1) portability, (2) light enough to permit manhandling in areas inaccessible to vehicles, (3) capable of spraying trees up to a 40-ft. height, or shorter trees, and (4) provide relatively even spray distribution.

We purchased a pneumatically operated aluminum mast composed of six telescoping sections. The length of the nested mast was

12 ft. and the extended length 50 ft. Each of the sections was keyed so that rotation of the bottom section also rotated the upper sections. The mast was mounted on a swivel base, so it could be positioned at any angle and held in place by guy lines, attached to a collar within which the mast rotated.

The design of the telescoping-pole sprayer called for a spraying system, attached to the top of the mast, that would treat a circular plot by rotation of the entire mast from the ground. The first spraying system was a boom consisting of two, 10-ft. sections of 3/4-in. aluminum pipe hinged so that each section could be folded along the mast (fig. 11.1). The mast was raised through a tree with the booms folded. The booms were then extended to a horizontal position (fig. 11.2) by means of arms activated by an air cylinder. The boom was equipped with 12 diaphragm nozzles of increasing size from center to end at 20-in. intervals so that approximately equal spray coverage was obtained throughout the plot radius.

A circular plot is unusual for research on spraying and equipment had not been developed to resolve the problems of such a technique. While rotating the mast, the end of the 10-ft. boom section would travel five times as far as would a point on the boom 2 ft. from center. Thus, spray delivery from nozzles would have to be progressively greater with increasing distance from center. Nozzle sizes were available that permitted a relatively even spray distribution throughout the plot radius.

The weight of the spraying system shown in fig. 11.2 was about 45 lb., so manhandling was not difficult. A plot with a diameter of 20 ft. could be treated with the system. Spray material was delivered to the boom by air pressure from a supply tank on the ground. The air supply was provided by a small portable compressor on air-supply tanks. The boom was calibrated to deliver 10 gal. per acre when the mast was rotated 180° in 3 sec.

The system was operable but had several disadvantages. (1) The mast extended to 50 ft. but the folded booms hung down 10 ft. so a 40-ft. tall tree was the highest that could be treated. Many trees we wanted to treat were taller than 40 ft. (2) The booms, nozzles, air cylinder for raising the booms, and spray solution put a lot of weight at the top of the mast. This caused considerable sway when the mast was rotated, and also put a strain on the mast that could cause early breakdown. (3) The inboard nozzles would start to spray earlier than the outboard as the boom filled,

Figure 11.1.--Telescoping-pole sprayer nested, with booms folded along the mast.

Figure 11.2.--Telescoping-pole sprayer extended with booms in horizontal position ready for spraying.

thus causing uneven spray application. (4) Plot diameter was only 20 ft. Most of the trees we wanted to treat had crowns more than 20 ft. in diameter. (5) When spraying was completed and booms folded, spray solution remaining in the boom would drip from nozzles as the mast was lowered. (6) The booms were a constant, potential source of breakdown because of snagging on limbs as the mast was lowered.

The disadvantages of the boom were sufficiently serious to cause consideration of a system that would treat larger trees with less potential for breakdown. Such a system would be advantageous even though evenness of spray distribution was sacrificed to some extent.

A new system was developed that alleviated or eliminated the disadvantages of the boom and nozzle system. We purchased a Boomjet[1] spray unit and modified it to even out spray distribution throughout the radius of a circular plot. The Boomjet required much less equipment at the top of the mast and was not as susceptible to breakdown as was the boom. The obvious disadvantage of the Boomjet was less even spray distribution.

Any system that sprays a relatively wide swath from a central point delivers small droplets at the center and increasingly larger droplets at greater distances from center. In our case, the problem was compounded by the requirement of a circular plot. To provide greater spray delivery toward the periphery of the plot, the Boomjet was modified to contain two OC-06 tips; four 0508 HE tips; and two 0006 tips (fig. 11.3). This system sprays a circular area 40 ft. in diameter as the mast is rotated 180°. The 180° arc is controlled by a limit switch, mounted at the base of the mast, that automatically activates a solenoid valve as the mast is rotated. Air pressure to the supply tank is supplied from a pressure-regulated tank on the ground.

[1] Spraying Systems Company, Inc.

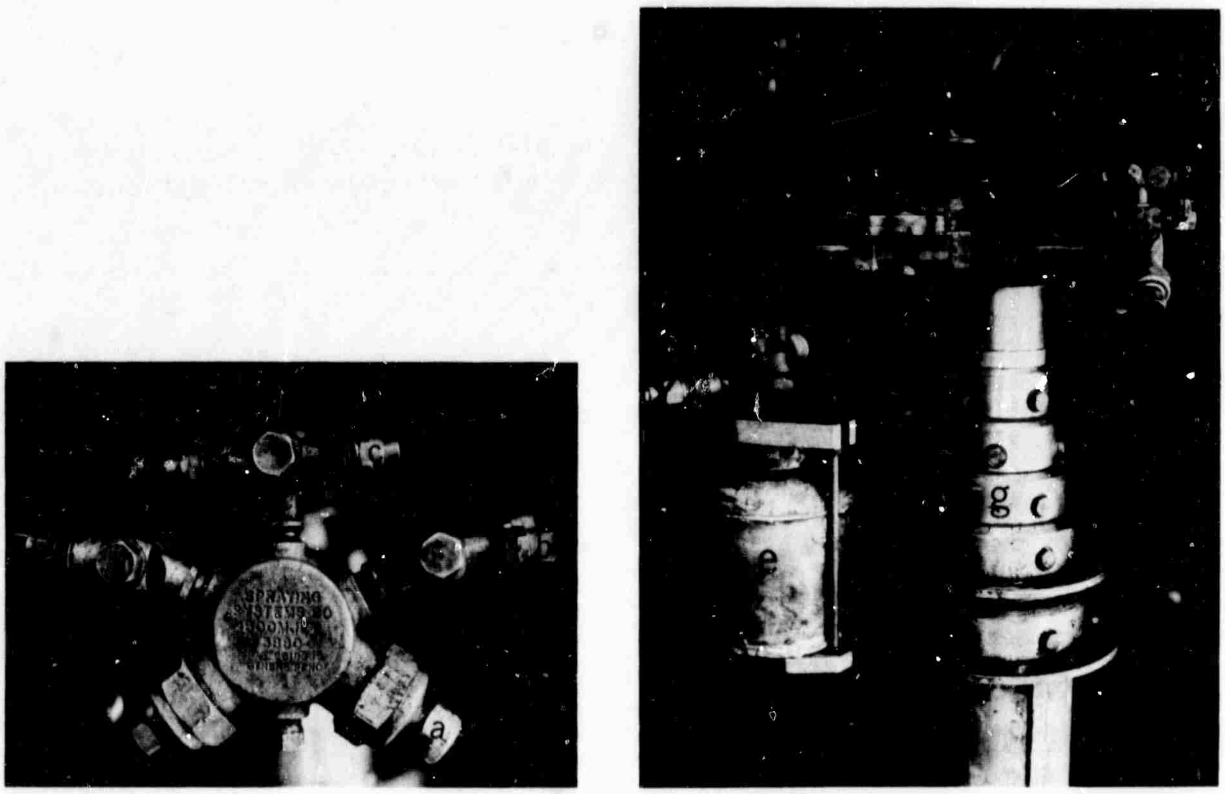

Figure 11.3.--Modified Boomjet: A, Face view and B, side view. (a) OC-06 tip, (b) 0508 HE tips, (c) 0006 tip, (d) solenoid valve, (e) spray supply container, (f) 1/4-inch air supply hose, and (g) nested mast.

The Boomjet was calibrated to deliver 10 gal. per acre at a pressure of 31 p.s.i. when the mast was rotated 180° in 3.5 sec.

Spray distribution patterns of the boom and nozzle and Boomjet systems were compared. Kromekote cards and aluminum plates, each 4 by 5 in., were placed at 2-ft. intervals from center along four radii extending 24 ft. from the mast. A 1-percent solution of nigrosine dye in water was used for comparing spray distribution of the two systems. The dye solution on kromekote cards was intended for a permanent record that could be used for visual comparisons. The dye collected on aluminum plates was washed off and analyzed colorimetrically to determine the volume of spray deposition. Analyses were made with a Bausch and Lomb Spectronic 20 colorimeter at 540 mμ.

Both systems deposited more spray near the center of the circular plot than at the periphery (fig. 11.4). Actual output for the boom and nozzle was near calculated output from 2 to 9 ft. along the radii and dropped off sharply for greater distances. Actual output for the Boomjet was near calculated output from 8 to 13 ft. along the radii, and then decreased steadily to 1.2 gal. per acre 20 ft. from center.

Droplet size for the boom and nozzle system was fairly uniform throughout the 10-ft. radius. With the Boomjet, mean droplet size was similar to that of the boom and nozzle for the first 8 ft., but rose sharply for the 10- to 20-ft. portion of the radius. Beyond 10 ft., the mean droplet diameter was slightly more than 700 μ, with a corresponding drop in number of droplets per unit area.

Although spray distribution from the Boomjet, in terms of droplet size and amount of spray deposited, was not as uniform as with the boom and nozzle system, the practical advantages of the Boomjet far outweighed the disadvantages. Advantages of the Boomjet include (1) a 40-ft. circular plot can be treated instead of 20-ft., (2) the Boomjet is lighter, easier to transport, and less susceptible to mechanical damage, (3) a 47-ft.-tall tree can be treated whereas 40 ft. was maximum for the boom and nozzle system, (4) drip was eliminated while the mast was lowered through a tree, and (5) less weight at the top of the mast resulted in less mast sway.

In practice, the telescoping-pole sprayer is transported to the field on a Jeep (fig. 11.5). If the trees to be sprayed are on flat terrain, the jeep can be backed under a tree, the mast extended, and spraying accomplished without taking the system off the jeep. Terrain was always steep in Puerto Rico, however, so the telescoping pole had to be manhandled. The mast was carried to the tree to be sprayed. The swivel base was placed in location and steel pins driven into the ground to hold it in place. The spray supply tank and air-hose were then attached to the spray unit, the

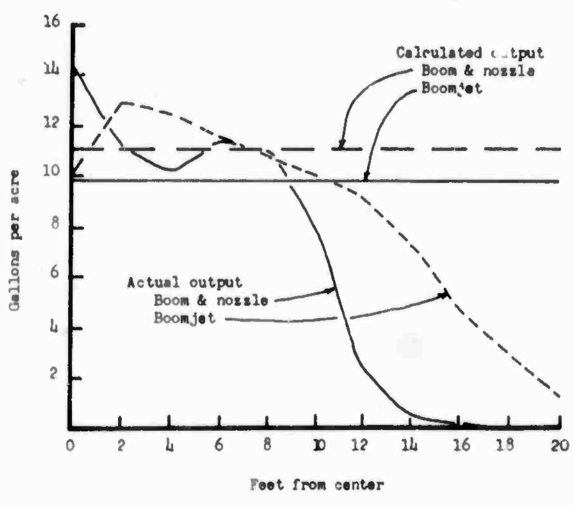

Figure 11.4.--Spray distribution in a circular plot obtained with Boomjet and boom and nozzle spraying systems mounted on a telescoping mast. Sample cards were placed 3 ft. below the spraying systems.

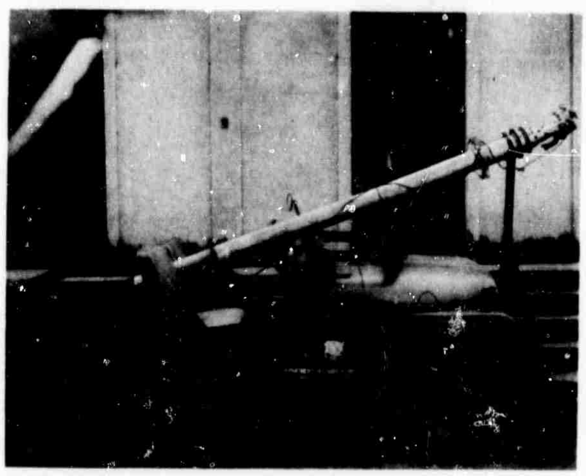

Figure 11.5.--Telescoping-pole sprayer mounted on jeep for transport to and from field plots.

mast raised to a vertical position and guyed with nylon rope. The mast was extended through the tree to the desired height and the solenoid valve connected to a 12-v. battery through a limit switch. The mast was then rotated through an arc of about 240° at a uniform rate, during which time the limit switch turned the solenoid valve on and off so that each half of the Boomjet sprayed an arc of 180°. The mast is then lowered and moved to the next tree. About 30 min. are required for each tree, including moving and setup time.

Laboratory Sprayer

A laboratory sprayer was needed for rapid and precise treatment of plants grown in greenhouse and growth chamber. Knapsack sprayers were not satisfactory because the application rate was not always uniform and because of contamination of laboratory and greenhouse areas. Consequently, a laboratory sprayer was designed which had the following features: (1) A spray chamber and drain pan to confine and remove excess herbicidal spray, (2) an activated charcoal air-filter system to prevent contamination by fumes, (3) a variable-speed spray cart (0 to 5 m.p.h.) mounted on an overhead track, and (4) a variable height, plant supporting tray. One or several potted plants up to 4 ft. in height could be treated at one time with single or repeated applications. The rate of application was controlled by nozzle speed, nozzle size, and spray pressure. Operation and cleaning procedures were simple.

An enclosed spray booth 4 ft. wide, 9 ft. high, and 16 ft. long was constructed (fig. 11.6). The frame consisted primarily of 2 by 2 in. ornamental steel tubing. A drain pan sloped from the ends of the spray booth toward the center. The center section of the drain pan (4 by 6 ft.) was recessed for a plant supporting tray consisting of a steel tubing frame covered with expanded metal. The plant support tray could be raised and lowered by a cable lift to adjust the distance below the spray nozzle from 2 to 6 ft.

A spray cart carried the spray nozzle and herbicide container the length of the spray booth (fig. 11.7). The cart frame was constructed of 5/16-in. thick aluminum plate and 1 by 1 in. lightweight steel tubing. Four 3-in. diameter nylon rollers supported the plate on an overhead track. The spray cart was propelled along the track by a mechanical linkage to a No. 50 steel roller chain carried on two 60-tooth sprockets located at either end of the

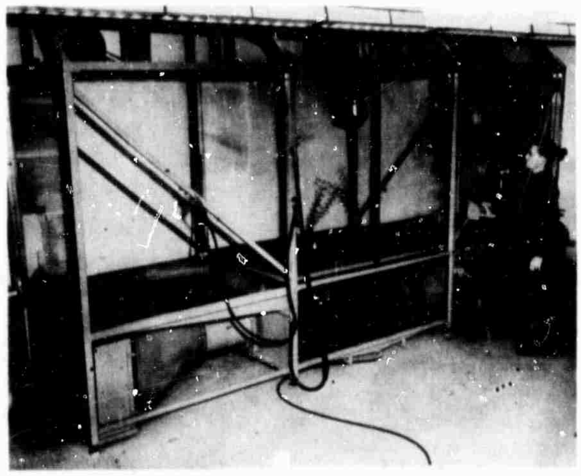

Figure 11.6.--Enclosed laboratory sprayer for potted plants.

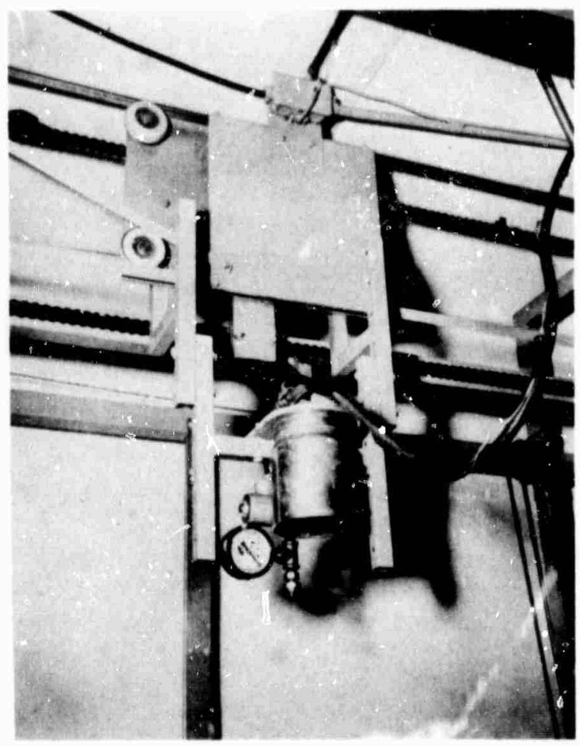

Figure 11.7.--Spray cart assembly mounted on overhead track.

track. The mechanical linkage consisted of a 1-1/2 in. diameter roller bearing fastened to an attachment link in the chain. The bearing operated in a vertical groove on the spray cart and carried the cart back and forth across the spray booth as the roller chain was driven continuously in one direction. The chain was driven by 1/2 hp. variable speed drive unit. The speed of the cart was controlled by a small hand wheel located on the front of the spray booth. A mechanical counter attached to the hand wheel shaft was calibrated to indicate cart speed in m.p.h. and ft. per sec. All exposed steel surfaces were painted with a chemically resistant epoxy resin.

The sprayer consisted of a 1-qt. pressurized spray can, an electric solenoid operating valve, a pressure gage, and a nozzle. Air pressure was supplied through a flexible rubber hose. A small glass bottle containing the herbicide 'ution was placed inside the pressurized spray can (fig. 11.8). The liquid inlet tube extended to the bottom of the bottle, permitting nearly all the material in the bottle to be sprayed. The entire spray system was flushed with clean water or solvent by attaching a hose to the end of the liquid inlet tube after the pressurized and herbicide containers were removed. Subsequently, the cleaning solution was removed from the spray system by an airhose attached to the same liquid inlet tube. The entire spray unit on the cart could be raised or lowered by adjustable brackets. Rate of application was readily calculated from the nozzle delivery rate and cart speed. Potted plants could also be sprayed when the spray cart was stationary.

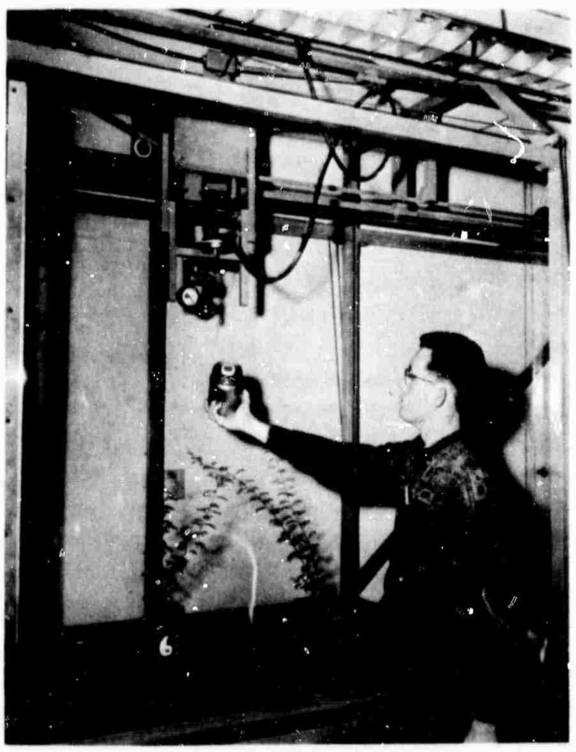

Figure 11.8.--Replacement of pressurized can containing glass herbicide container.

The spray booth sides were enclosed with 3/16-in. thick transparent plastic panels to confine the spray particles. Two 5-ft. high by 3-ft. wide sliding doors provided access to the plant supporting tray, sprayer unit, and interior of the booth. In addition, two 3-ft. wide by 2-ft. high doors below the larger doors could be opened to provide a large opening for placing large plants into the booth. An exhaust fan was installed under one end of the drain pan to draw air containing herbicide particles out of the booth through a louvered opening in the drain pan and force it through an activated charcoal filter system. Clean air entered the booth from the top. The exhaust fan was operated as soon as spray droplets were deposited after each spraying operation. An automatic-reset interval timer was used to assure that adequate time was allowed for air in the booth to be replaced with clean air. This system was very effective for preventing herbicide contamination.

Manual or automatic control of the spray cart and solenoid valve was provided on a control panel on the front of the booth. Trip blocks attached to the drive chain activated a snap switch to provide automatic cart and spray valve operation. The automatic spraying distance was varied by repositioning the trip blocks. Air pressure for spraying was adjusted with a pressure regulator at the control panel. An air valve for turning air into the pressurized spray container also released air pressure from the container when in the off position.

Droplet Producing Devices

Information concerning the drop-size distribution of sprays is often obtained by collecting dyed spray samples on paper. The spray droplets create colored spots on the sampling surface and are then measured and counted. In order to predict the size of the spray droplet which created a particular spot on the sampling surface, the relationship between droplet size and spot size must be known. This relationship is termed the spread factor. Since spread factors vary for different sizes of spray droplets, different types of sampling material, and different types of spray materials, information on the type of sampling surface and spray material used must be available for a range of droplet sizes sufficiently large to include the droplets in the spray being studied. A device or devices were required that would produce uniformly sized droplets having known diameters. Droplets produced could then be deposited on sampling surfaces and spread factors obtained. Spread factors were needed for droplets ranging in diameter from approximately 15 to 5,000 μ.

Several investigators had constructed vibratory devices for producing droplets of uniform size, ranging from 6 to 400 μ in diameter. These devices consisted of vibrating reeds or blades with pointed or needle-shaped tips that passed through a drop or small quantity of liquid clinging to a capillary or other liquid feed unit. The reed or blade was made to vibrate in tune with alternating current passing through an electromagnet, which caused the pointed end of the reed or blade to pass through the liquid drop held on the feeding device. Drops of uniform size were dislodged. A 60-cycle current caused the reed to vibrate at 120 vibrations per second, thus dislodging 120 drops per second.

A rotary device for producing a stream of uniform drops had also been developed to produce uniform drops with diameters ranging from 50 to 700 μ. This device consists essentially of a horizontally rotating blade passing through a stabilized liquid mass held in a specially constructed liquid feed unit by liquid surface tension. As the rotating blade passes through the liquid, it dislodges a steady stream of uniform sized droplets. The rate of droplet production is controlled by varying the r.p.m. of the rotating blade. The size of the droplets produced is controlled by both blade speed and blade shape.

Vibratory droplet production device.--A vibratory apparatus was constructed for producing uniformly sized droplets (fig. 11.9).

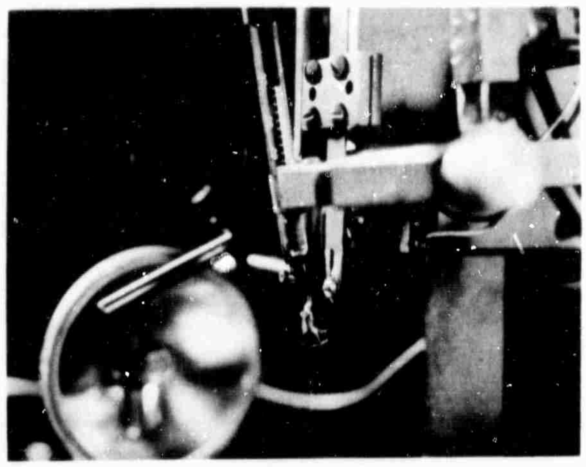

Figure 11.9.--Vibratory droplet production device.

This device consisted of an electromagnet and a short length of hacksaw blade with a needle attached to its end. The electromagnet was powered with 110 v., 60 c., a.c. current, which caused the blade to vibrate at twice the current frequency. The needle pierced a liquid droplet held in a feeding device constructed of aluminum. This device, similar to others reported in the literature, produced single streams of water droplets ranging in size from 100 to approximately 380 μ in diameter.

To obtain accurate measurements of actual drop diameters, photographs were taken of the droplets immediately after they were formed. An extension tube was constructed and attached to a 4 by 5 in. press camera to permit photographs with a 5X magnification. The droplets were photographed while falling through the air. An electronic stroboscope provided a high-speed light source to stop the motion of the droplets on film. Polaroid packet film was used so the photographic results could be seen immediately. When the droplet producing device was adjusted to provide the drop size desired, a photograph was made and at the same time, droplets were collected on spray

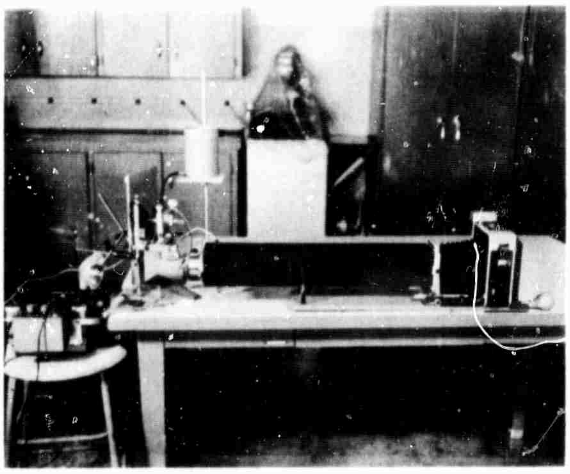

Figure 11.10.--Press camera with extension tube and strobe light.

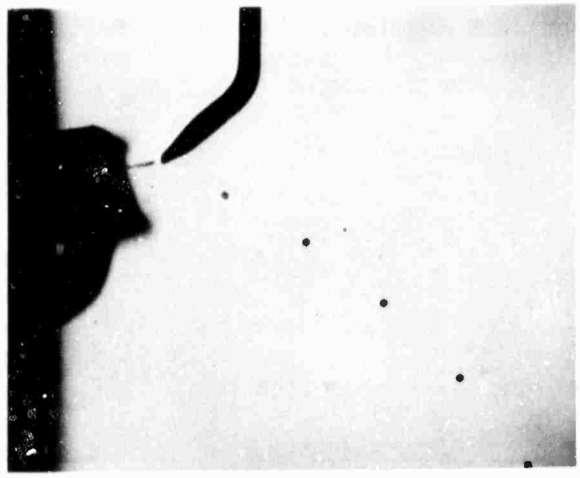

Figure 11.11.--Water droplets formed with the vibratory unit (3.5X).

sampling cards for use in spread factor determination. Figure 11.10 shows the camera and strobe light and figure 11.11 is a 3.5X magnification photograph of a stream of droplets being produced by the vibratory unit.

Rotary droplet production device.--A rotary droplet producing device was constructed by using a small variable speed drive unit to turn a rotating spindle to which a small stainless steel blade was attached (fig. 11.12). Stainless steel blades approximately 1/4-in. wide, 1-1/4 in. long, and 0.024-in. thick, clamped to the end of the 1/2-in. shaft, were rotated at speeds ranging from 450 to 4,700 r.p.m. The tips of the blades were filed and ground into special shapes and the speed of blade rotation varied to produce different diameter droplets. The technique used to obtain spread factors was to adjust the drop producing device and liquid control rate so that a steady stream of uniform diameter drops was produced. The droplet diameters were measured photographically as explained for the vibratory unit. Uniform diameter water droplets ranging from 200 to 950 μ were produced with the rotary device.

Other droplet production methods.--Streams of uniform diameter water drops were also produced by flow through a hypodermic needle modulated with a minature 8 to 20 v. a.c. electromagnetic reciprocating pump (fig. 11.13). Hypodermic needles with sizes ranging from No. 30 to No. 18 were attached directly to the output side of the pump. Water pressures ranging up to 24 p.s.i. were applied to the inlet side of the pump. Droplet size and the rate of droplet production was regulated by varying the water pressure, needle size, and pump speed. Power for the pump was supplied by an audio amplifier driven with an audio signal generator. Drop diameters produced ranged from approximately 500 μ using a 30-gage needle with 24 p.s.i. and a pump speed of 540 c. per sec., to approximately 1,800 μ using an 18-gage needle with 6 in. of water pressure and a pump speed of 110 c. per sec.

Brief attempts to produce streams of uniform drops of thickened spray material by the methods mentioned previously were unsuccessful. Uniform drops of thickened sprays, ranging from 900 to 3,000 μ in diameter for invert emulsions and 1,800 to 4,600 μ for particulated spray material, were obtained by forcing the material through small pipettes. Various combinations of liquid pressure and pipette size were used to obtain different drop diameters. Carmine 2B dye was added to the liquid and a suitable number of drops collected on both kromekote spot card paper and on mylar sheets. Actual drop diameters were determined by counting the drops on the mylar and then determining the total volume by colorimetric techniques. The diameter was then calculated from the volume per drop.

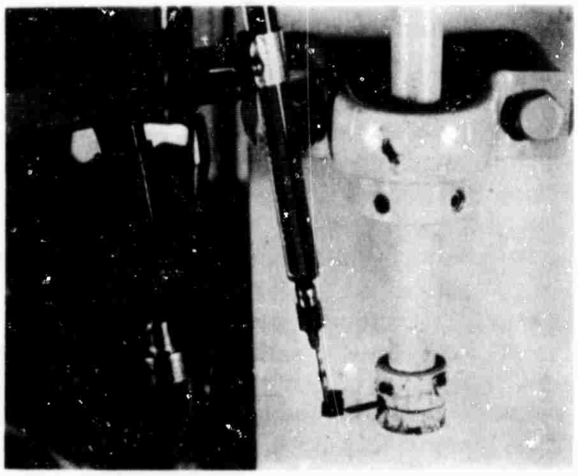

Figure 11.12.--Rotary droplet production device showing spindle, blade, and liquid holder.

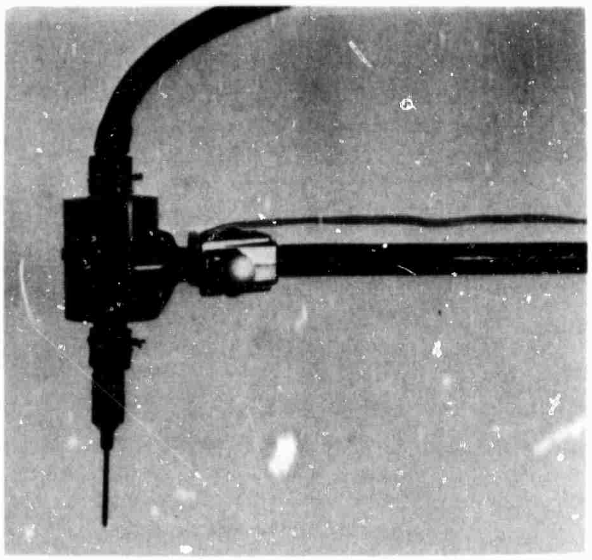

Figure 11.13.--Minature reciprocating pump for modulating jet stream from needle to form uniform water drops.

Manual Drop Measuring and Counting Instrument

One technique for obtaining drop-size distributions from photographs and spot cards is to count and record the number of drops or spots in size classes or increments of a selected width. Frequency distribution graphs may then be plotted and various median and mean diameters and standard deviations obtained. Methods of measuring and counting drops or spots have ranged from slow laborious measurements with low-power microscopes equipped with measuring reticles to high-speed electronic scanning devices, such as the flying-spot-particle-analyzer[2]. Samples analyzed with the flying-spot-particle-analyzer must be in the form of 35 mm. transparencies which provide a high degree of contrast between the spot being measured and the background. The drop images must also have well-defined edges in order to obtain satisfactory counts.

Negatives of spray drops in free flight in the low-speed wind tunnel did not provide sufficient contrast or sharply defined drop edges required for analysis with the flying-spot-particle-analyzer. A technique for measuring and counting drops from wind tunnel studies was therefore needed. Also, since the flying-spot-particle-analyzer was not readily available for use, equipment was needed for analyzing spot cards where the number of samples was limited. Therefore, a manually operated drop measuring and counting instrument was constructed.

Figure 11.14 shows the general arrangement of the equipment. Droplet photographs and spot cards were magnified with a micro-projector to obtain either 10X or 20X images on the ground-glass screen. Transmitted light was used for transparencies and reflected light for spot cards. The images were placed in size classes by adjusting a set of specially constructed calipers mounted on a switchbox to the image diameters and pressing a pushbutton switch. This process was repeated for each spot counted. Adjustment of the spacing between the arms of the caliper caused a rotary selector switch to make contact with one of 30 poles which were in turn wired to 30,

[2] Airborne Instruments Laboratory, Deer Park, L.I., N.Y.

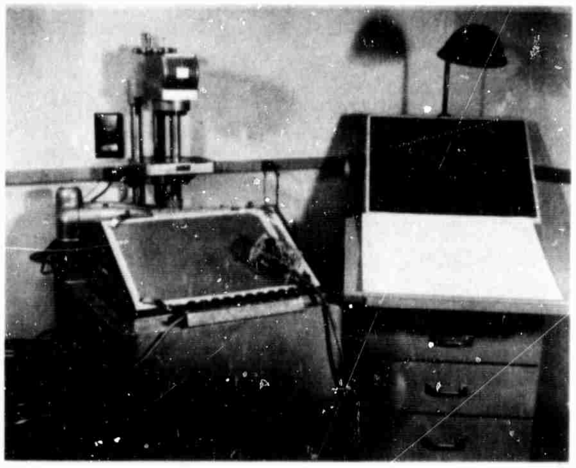

Figure 11.14.--Manual drop measuring and counting equipment.

4-digit, manual-reset, electric counters. Pressing the pushbutton switch completed the circuit to a single counter causing a count to be registered. The rotary switch was connected to the caliper arms through small spur gears and a rack and pinion system (figs. 11.15, A and B). The gear sizes were selected so that changing the rotary switch position one increment caused a caliper arm movement of exactly 1 mm. In addition to the rotary switch and caliper measuring and counting system, separate pushbutton switches were provided to register counts on the 10 counters corresponding to the 10 smallest size classes. This permitted direct registering of drops or spots measured visually with the aid of gridlines on the ground-glass screen.

The drop measuring and counting instrument was used to obtain drop-size distributions from several thousand spot cards collected during spray distribution and spray penetration studies. It was also used to obtain the drop-size distribution from negatives of spray drop formations in the low-speed wind tunnel. Although manual drop measurement with this device was time consuming, it was much faster than many other manual methods. It also satisfied the need for a measuring technique for those samples which could not be analyzed with the flying-spot-particle-analyzer. Both the flying-spot-particle-analyzer and the manual instrument were used to evaluate spot cards from the study concerning spray penetration through post oak and yaupon foliage canopies.

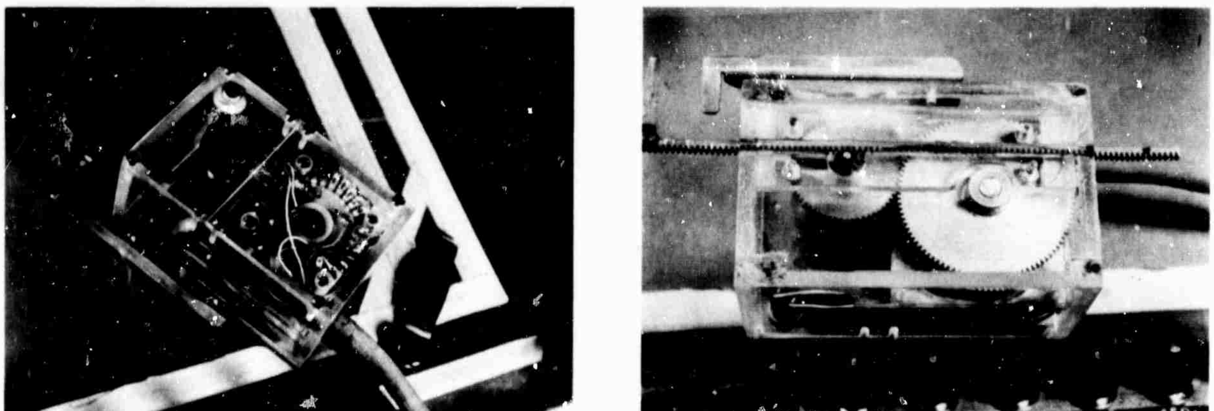

Figure 11.15.--Top view of drop measuring instrument showing A, Rotary switch and B, caliper adjustment.

Timed-interval Photographic Equipment

An important criterion in selecting a herbicide and its time of application could be the length of time required to obtain plant response. A photographic apparatus for making closeup color photographs of plants at preselected timed intervals was needed to study the speed of response of potted plants to various herbicidal treatments. The requirements for such a device included that it be capable of making photographs of either one, or more than one, plant at a time so that either single or multiple treatments could be studied. Additional requirements were that operation be automatic and that the time-interval between photographs be easily varied from a few minutes to several hours.

A 35 mm. camera with an electric motor drive for advancing the film was used to provide automatic camera operation. Closeup attachments were used to obtain reproduction ratios greater than those possible with the 50 mm. f-2 lens alone. Two closeup attachment lenses and two extension rings could be used individually or in combinations to provide reproduction ratios up to approximately 1:1.2. An extension bellows provided reproduction ratios of 1:1 to approximately 3.5:1 (3.5X magnification). The camera could also be used to provide timed-interval photomicrographs, if necessary. An electronic flash unit with a 1/1000-second flash duration provided light for the photographs. This unit was recharged on 110 v. a.c. and kept in a fully charged condition by leaving it plugged in during a series of exposures. After the flash occurred, the unit regained its fully charged state in approximately 10 seconds.

A 36-inch diameter turntable was constructed to support from one to six potted plants and to permit photographs of more than one plant within a short period of time. In operation, the camera was mounted on a tripod and adjusted to focus on a single plant on the turntable (fig. 11.16). A timeclock caused the turntable to rotate one complete revolution at preselected timed intervals. As the turntable rotated, six trip blocks located on the turntable shaft, operated a microswitch once for each 60° of table rotation. The microswitch controlled the motor-driven camera causing six exposures to be taken. The six plants were positioned at approximately 60° intervals around the turntable so that they were in focus and properly framed as the exposures were made. If less than six plants were to be photographed, some of the trip blocks were removed so that the microswitch was operated and exposures made only for turntable positions containing plants. The turntable was driven with a 2 r.p.m. motor through a set of spur gears which reduced the turntable's speed to approximately 0.62 r.p.m. (fig. 11.17)

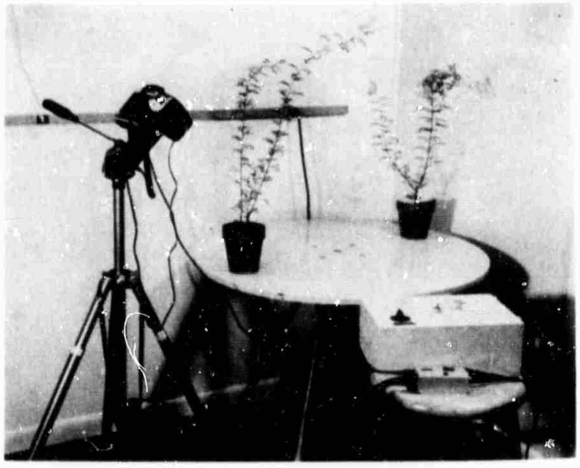

Figure 11.16.--Timed-interval photographic equipment and turntable.

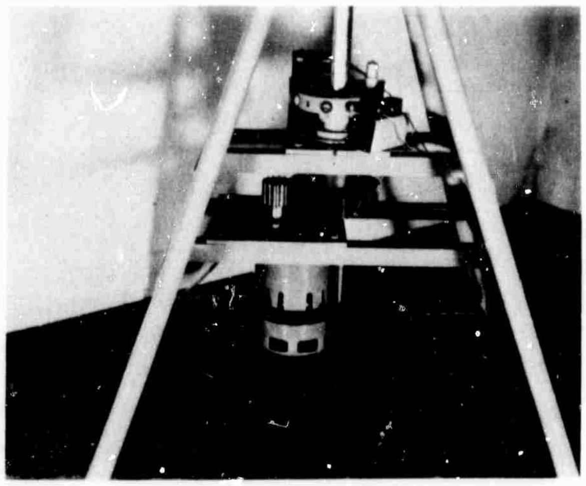

Figure 11.17.--Turntable drive unit and switches for controlling table operation and actuating camera.

Reproduction ratios were limited when using the turntable since increasing the reproduction ratio decreased the depth of focus and focusing became very critical. A slight movement of the object, toward or away from the camera, resulted in the object being blurred or perhaps completely out of focus. Reproduction ratios of 1:1.23 were used when photographing leaves of single plants, although normal plant movement, such as drooping or closing of the leaves, necessitated periodic refocusing. A reproduction ratio of 1:5.5 was used successfully with the turntable.

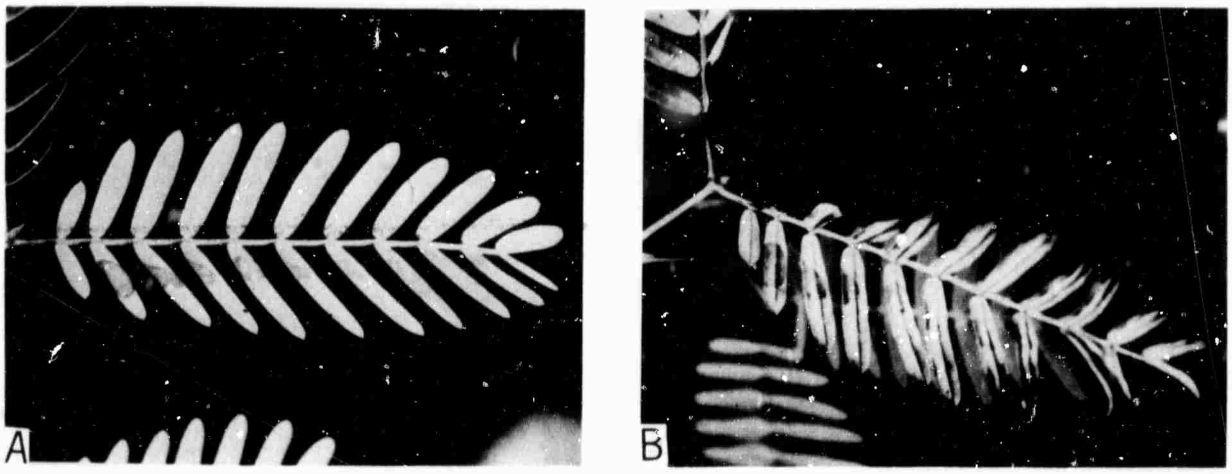

Figure 11.18.—Mesquite tertiary leaflets photographed with the timed-interval device: A, immediately after treatment with 100 p.p.m. paraquat and B, the same leaflet 18 hours later.

The control circuit for providing the timed-interval photographs included a series-repeating timer with a 60-minute dial cycle. This timer, which provided a minimum on- or off-interval of 60 sec. through the use of 60 tilting trippers, was used to increment a 21-pole stepping switch. The poles on the stepping switch were wired to the contacts of a 21-position selector switch. This combination provided numerous timed-interval possibilities ranging from 1 min. to 21 hr. for single plant photographs and from 2 min. to 21 hr. for turntable photographs. One minute turntable intervals were not possible since the turntable speed was only 0.62 r.p.m. A normally open, 2-second delay, time-delay relay was used to reset the stepping switch for single plant photographs and a cam operated snap switch was used for resetting after one complete revolution when taking photographs of plants on the turntable. Another snap switch, operated on a slightly longer cam, was used to move the turntable an additional short distance to assure that the resetting snap switch opened before the table stopped.

Photographs made with the timed-interval apparatus indicated that operation was satisfactory, provided proper care was exercised in adjustment and operation. Periodic refocusing was necessary due to normal plant movement when high reproduction ratios (short depth of focus) were used. Figure 11.18, A, is a print made from a colored slide of mesquite tertiary leaflets immediately after treatment with 100 p.p.m. of paraquat solution and figure 11.18, B the same leaflet 18 hr. later.

Spray Formation in Airstreams

The control of droplet size from both aerial and ground applications is highly important in the application of liquid herbicides. Small droplets are subject to evaporation and to drift by even the mildest air movements. Drift reduces the rate of intended treatment on the target area and also may result in damage to susceptible crops located downwind from the treatment area.

The concern about drift has led to the use of thickened spray materials that produce larger drops and lessen the probability of drift. Unfortunately, not all of the small droplets are eliminated by thickening the spray solution. Moreover, large droplets are undesirable if they are so large that the number of droplets per square inch on leaf surfaces is reduced to less than about 72.

This study was designed to investigate the factors affecting atomization of aerially applied sprays. The principle variables to be studied included airspeed, physical properties of the spray material, physical dimensions and shape of the nozzle or other atomizing device, angle of introduction of spray into the airstream, and nozzle pressure. The research was conducted in a small, low-speed wind tunnel where a single spray nozzle could be observed and aerial spraying speeds simulated. All the variables to be investigated could be easily controlled in the wind tunnel.

Equipment Used in Tests

Wind tunnel.--The wind tunnel had a 12 by 12 by 36 in. long horizontal test section. Walls of the test section were made of 1/2 in. thick transparent plastic to permit observation of spray formation. Air was drawn through the tunnel with a centrifugal fan powered by a 3,600 r.p.m., 25-hp. electric motor (fig. 11.19). Air velocity in the test section could be varied from 0 to 125 m.p.h. by regulating the air discharging from the centrifugal fan with a sliding gate. Air velocity in the tunnel was measured indirectly by measuring the static pressure in the intake air nozzle and converting to velocity by use of the Bernoulli equation. For standard air, the velocity in feet per minute is $4005 \sqrt{VP}$, where VP is the velocity pressure in inches of water. Velocity pressure was assumed equal to static pressure since the nozzle coefficient, for practical purposes, was unity.

Spray system.--A diaphragm-cutoff spray nozzle was attached to a removable door in the top panel of the test section (fig. 11.20). Nozzle angle was varied by means of a swivel connector. Spray liquid was fed to the nozzle from a 10-gal. pressurized paint container. Spraying pressure was varied by regulating the liquid pressure in the spray line above the wind tunnel. The air pressure on the liquid container was also regulated. This pressure system was used successfully for spraying conventional water and dye solutions, water particulated with Norbak (a polymeric particulating agent), water thickened with Dacagin (a pseudoplastic spray gel agent), and water thickened with Vistik (a high-viscosity hydroxyethyl cellulose).

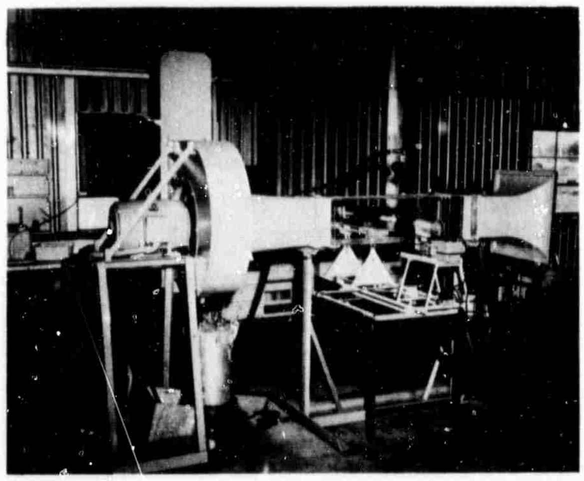

Figure 11.19.--Low-speed wind tunnel used in spray formation studies.

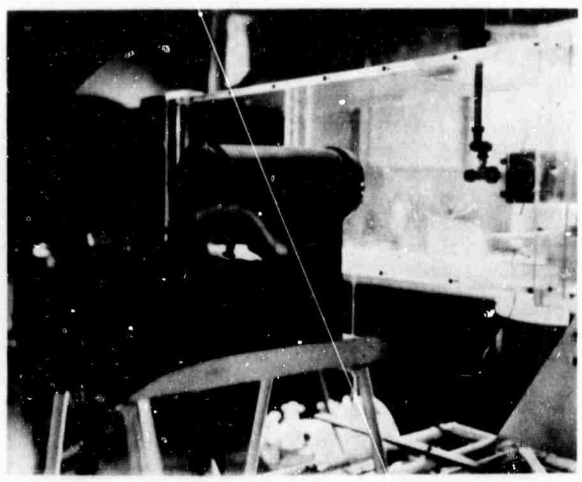

Figure 11.20.--Diaphragm type of spray nozzle positioned in wind tunnel test section.

A No. 4664 diaphragm-cutoff teejet nozzle body with a D10 orifice and No. 45 core was used most commonly. In addition, exploratory studies were made with a perforated metal plate in the nozzle body instead of the conventional orifice and core. Perforated plates with 3.5 percent open area and 0.008 in. diameter holes and plates with the same percentage of open area, but with 0.013 in. diameter holes, were tested (fig. 11.21). A relatively low pressure of 5 p.s.i. was used for most of these studies. The perforated-plate nozzles produced a jet stream type of atomization.

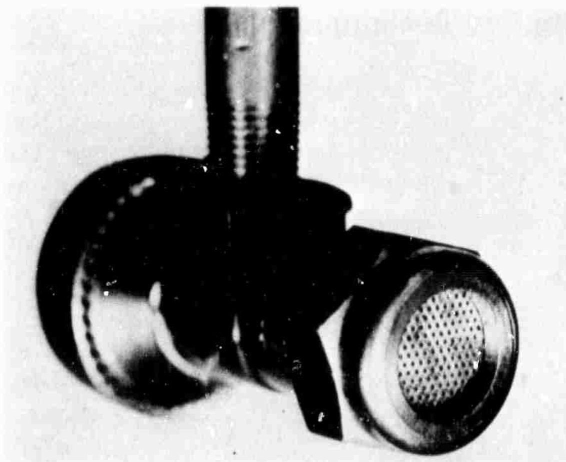

Figure 11.21.--Perforated metal plate in No. 4664 Teejet body.

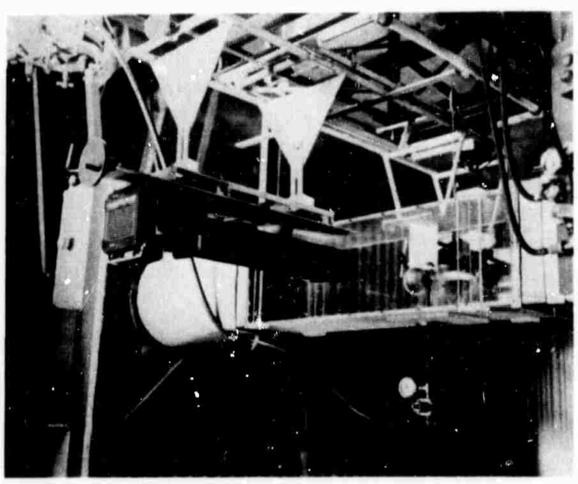

Figure 11.22.--Wind tunnel test section and 5X magnification camera.

Photographic sampling.--Spray atomization was observed through the transparent sides of the wind tunnel test section. Samples were obtained by means of high-speed silhouette photography. A 4 x 5 in. press camera, fitted with a specially constructed extension tube to provide 5X magnification, was positioned on one side of the test section directly opposite a high-speed light source (fig. 11.22). A 135 mm. f-4.5 lens with a between-the-lens shutter was mounted on the extension tube. The length of the extension tube was determined by the degree of magnification needed and the focal length of the lens. The actual size of the area photographed was approximately 0.8 in. wide and 0.7 in. high. Image and object distances (lens to film and lens to object distances, respectively) were calculated for a magnification factor of five from the following equations: (1) $1/F = 1/I + 1/O$ and (2) $I/O = M$ where F = focal length of the lens, I = image distance, O = object distance, and M = magnification factor.

From those relationships,

$$O = F(1 + 1/M) = 5.315\ (1 + 1/5) = 6.378 \text{ in.}$$

and

$$I + F(1 + M) = 5.315\ (1 + 5) = 31.890 \text{ in.}$$

Therefore, when the object was in focus at a point 6.378 in. from the lens, an image distance of 31.890 inches was required for a magnification of 5X.

The object distance of 6.378 in. permitted the lens to be focused on any point from the inside wall of the wind tunnel (on the camera side) to approximately the centerline of the tunnel. In order to assure that photographs could be obtained at points slightly beyond the centerline of the spray pattern, the nozzle was mounted so that it could be positioned approximately 5 inches from the wind tunnel wall. Depth of field calculations were made for f values of 4.5 and 16 since focusing was ordinarily done at f-4.5 and exposures at f-16. The depth of field was found to be 0.040 inch at f-4.5 and 0.142 in. at f-16.

A high-speed electronic stroboscope provided a high-intensity, short duration flash that "stopped" spray drop motion and permitted single-flash photographs. A 4-in. diameter condensing lens with a 16-in. focal length was positioned in a tube 12 in. from the stroboscope reflector to provide a spot of high intensity light at the camera lens. Flash duration measured at one-third peak intensity was approximately 0.8, 1.2, and 3.0 μ sec. for high, medium, and low speed ranges, respectively. Use of a photoelectric pickoff and time-delay unit permitted the light to be triggered with the camera shutter. A specially designed supporting table provided for adjustment of the horizontal, vertical, and lateral positions of the camera and light unit with respect to the spray nozzle.

Test Procedure and Sampling Technique

After considerable trial and error, a satisfactory film, shutter speed, f-stop setting, and light intensity were selected. In searching for a suitable film, several comparisons were made between Kodak Tri-X Pan with an ASA Index of 320, and Kodak Contrast Process Ortho, a very high contrast, fine-grain film with an ASA Index of 50 for tungsten and 100 for white flame arc. Other films were also tried. Equally satisfactory negatives were obtained using the Tri-X and Contrast Process Ortho films. The addition of nigrosine dye (1 percent solution) to the spray liquid provided improved drop-edge definition. A shutter speed of 1/60 sec. was used for all photographs since this reduced extraneous backgound light to a low level but still provided a sufficient length of time for the strobe to be flashed, while the lens was open, using a photoelectric pickoff and time-delay unit. When using Contrast Process Ortho film, the electronic flash was adjusted for high intensity and the f-stop set at 16. Medium intensity light was used with an f-stop of 16 when exposing the Tri-X film. The Tri-X film in packs was somewhat more convenient than the Contrast Process Ortho, which could only be obtained in sheets. Polaroid Type 52 film packets, which could be processed immediately, had about the same exposure index as Tri-X and were extremely useful in determining correct exposures and light settings. These packets were used in the 4 x 5 in. press camera with the aid of a special film-holder.

Before conducting a test, the camera was focused on some preselected sampling zone. In selecting zones for sampling, a visual inspection of the entire spray pattern was first made with the camera shutter open and the strobe flashing at a high rate (approximately 4,000 to 10,000 c. per min. was satisfactory). This provided an image on the ground glass at the film plane for each flash and gave the effect of continuous scanning of the object area. The supporting table adjustments were then used to "locate" the entire spray pattern. Sampling zones (0.8 by 0.7 in. by depth of focus) were selected within the spray pattern. The location of the center of the selected sampling zones in relation to the center of the spray-nozzle orifice was determined and recorded. When a sampling zone was selected and the camera positioned to focus at that zone, the shutter was closed and cocked and the strobe light set for single flash. Film was then inserted in the camera and exposed by tripping the shutter, which automatically caused a synchronized single flash of the strobe light. The 5X magnification negatives thus obtained were evaluated with the aid of drop- and spot-sizing equipment described elsewhere in this chapter.

Test Results

Investigation of sprays in a low speed wind tunnel by high speed "stop action" photography produced much interesting information about spray atomization. For example, tests on the atomization of water, spray material particulated with Norbak, and spray material thickened with Dacagin illustrate the extremely varied types of atomization obtained with different spray materials (fig. 11.23). Spray droplets are larger for the thickened materials, but fine droplets are still present. The stringlike character of the spray obtained from water thickened with Dacagin suggests that the threads would coalesce after leaving the airstream to form large droplets.

Droplet formation through a perforated-plate nozzle was studied at distances of 2, 5, and 8 in. from the nozzle. Comparative tests were made in still air and in an airstream of 75 m.p.h. (figs. 11.24, 11.25, and 11.26). The effect of the windstream is readily apparent 2 inches from the nozzle, but less apparent at greater distances. There is some suggestion that larger droplets are produced in the airstream due to coalescence of small droplets.

Comparison of the median diameters and standard deviations shown in table 11.1 indicate that for the hollow cone nozzle, samples obtained close to the nozzle had larger mass median diameters (MMD) and MMD standard deviations than samples obtained further away. This trend appears to be reversed for the numbers median diameter (NMD) and NMD standard deviation indicating that the drop diameters were more uniform at 8 than at

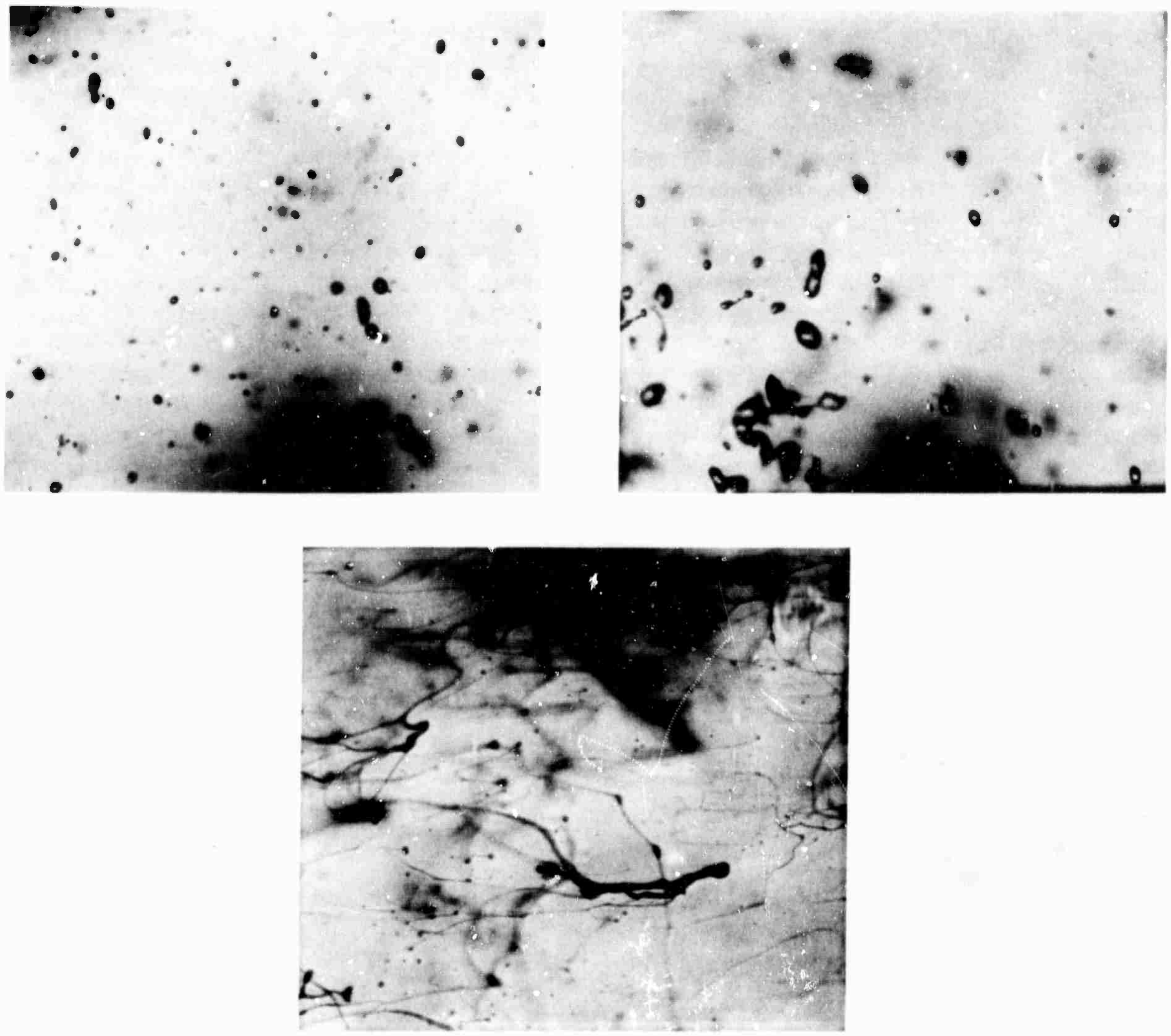

Figure 11.23.--Type of spray produced by various liquid materials when a hollow cone nozzle was oriented with the airstream: (A) water, 30 p.s.i., 75 m.p.h. airstream, (B) water with Norbak, 45 p.s.i., 120 m.p.h. airstream, (C) water with Dacagin, 30 p.s.i., 120 m.p.h. airstream.

2 in. This apparent improvement in drop diameter uniformity may be due to the fact that less drops were in focus because of greater drop dispersion at the 8-in. sampling distance than at the 2-in. sampling distance. It is possible that the airstream produced a winnowing effect which caused separation of the drops according to size with the larger drops moving to the outside of the cone pattern and the small drops being displaced to the inner portion of the cone pattern.

Comparisons of drop-size data from the hollow cone nozzle to that from the perforated-plate nozzles show that the MMD and NMD standard deviations were much smaller for the perforated-plate nozzles. This fact, along with visual comparison of the photographs, indicates that the perforated-plate nozzles produced sprays having more uniform drop sizes than sprays produced with the hollow cone nozzle. In addition, little difference was found between the drop data from the 0.008-in. diameter hole size perforated-plate in still air or in a 75 m.p.h. airstream. Photographs of spray from the 0.013-in. diameter hole plate revealed MMD's and NMD's

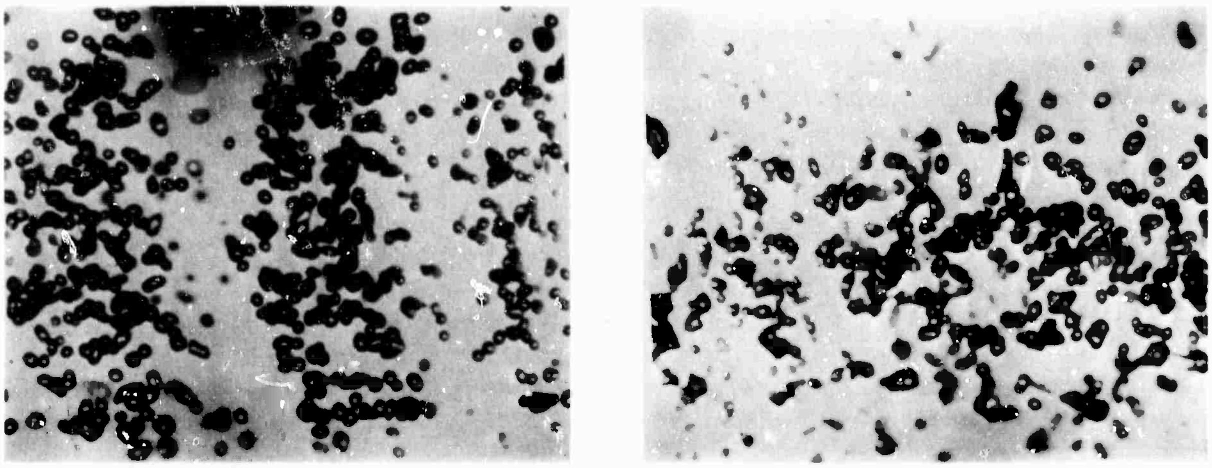

Figure 11.24.--Water spray produced through a perforated-plate nozzle having 0.008 in. diameter holes at 5 p.s.i., 2 in. from the nozzle: (A) Still air and (B) 75 m.p.h. airstream (3.5X).

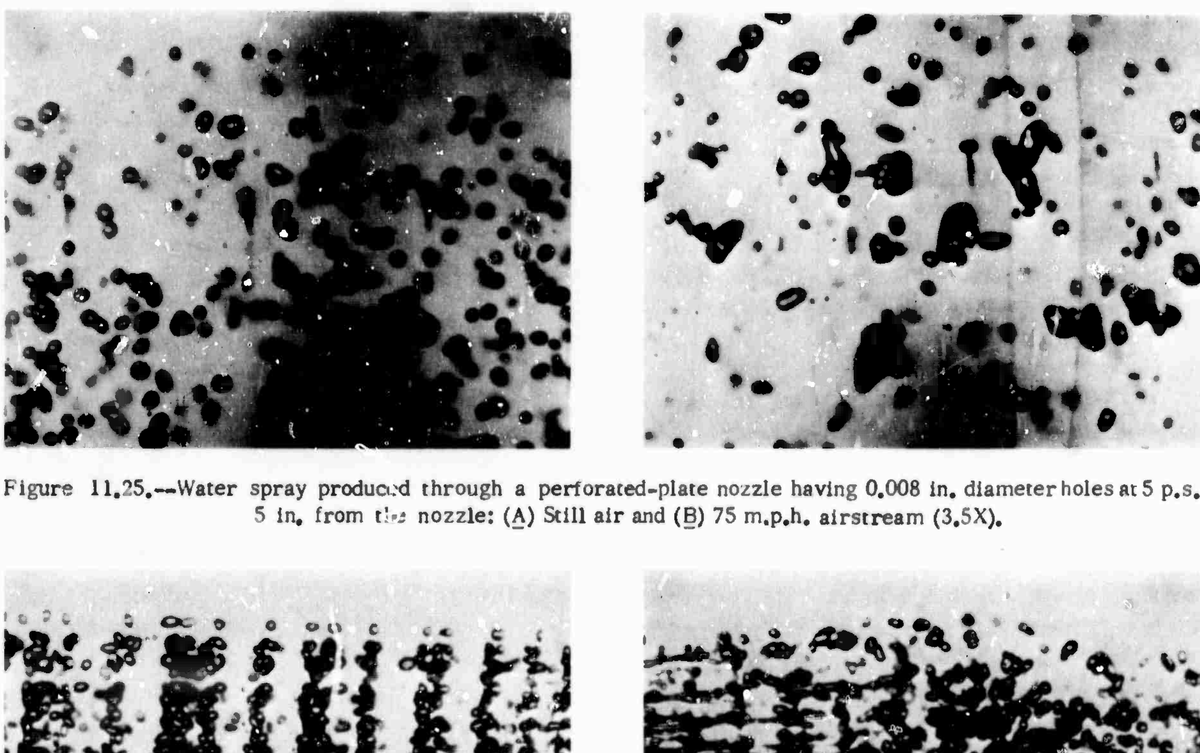

Figure 11.25.--Water spray produced through a perforated-plate nozzle having 0.008 in. diameter holes at 5 p.s.i., 5 in. from the nozzle: (A) Still air and (B) 75 m.p.h. airstream (3.5X).

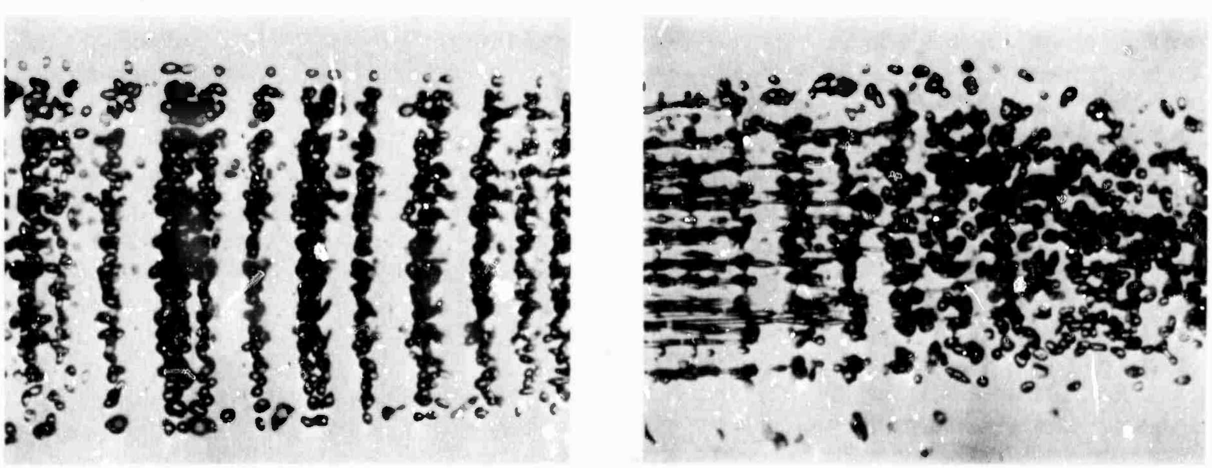

Figure 11.26.--Water spray produced through a perforated-plate nozzle having 0.008 in. diameter holes at 5 p.s.i., 8 in. from the nozzle. (A) Still air, (B) 75 m.p.h. airstream (3.5X).

TABLE 11.1.--Water spray drop-size data from wind tunnel

Air velocity	Spray pressure	Distance downwind from nozzle	MMD	MMD Std. Dev.	NMD	NMD Std. Dev.
M.p.h.	P.s.i.	In.	μ			
HOLLOW CONE NOZZLE No. 4664-D10-45[1]						
75	10	2	587	602	128	233
75	10	5	590	460	167	311
75	10	8	560	408	199	311
75	30	2	737	752	120	230
75	30	5	610	518	170	264
75	30	8	538	418	223	283
No. 4664 TEEJET WITH 0.008 INCH (200 μ) HOLE SIZE PERFORATED PLATE[2]						
0	5	2	358	129	320	149
0	5	5	460	175	409	168
0	5	8	534	315	483	187
75	5	2	364	107	309	226
75	5	5	473	252	386	191
75	5	3	527	340	407	245
No. 4664 TEEJET WITH 0.013 INCH (330 μ) HOLE SIZE PERFORATED PLATE[2]						
0	5	2	518	172	420	368
0	5	5	562	342	471	213
0	5	8	662	253	560	252

[1] Drop-size data for the hollow cone nozzle are mean values from three sampling locations at each downwind distance and three to five replications from each location.

[2] Drop-size data for the perforated plate nozzle are from one sample location only at each downwind distance and one replication only.

ranging from 60 to 160 μ larger than for the 0.008 in. diameter hole plate. The increase in both MMD and NMD with an increase in downstream sampling distance was thought to be due to coalescence of the spray drops. This problem could probably be corrected by using a slightly convex perforated-plate in the nozzle. The MMD's of the spray samples from the perforated nozzles ranged from 1.6 to 2.7 times larger than the orifice diameters and the NMD's ranged from 1.3 to 2.4 times larger than the orifice diameters.

Spray Penetration and Distribution

The penetration and distribution of spray through forest canopies was studied in both Puerto Rico and Texas, Although the two areas are widely separated geographically, the forests themselves are similar in terms of physiognomy.

The test site in Puerto Rico is typical of a moist tropical forest formation. The area had been in coffee production for many years, and coffee still forms the principal constituent of the understory. Citrus is common, and a few bananas and mangos are present. There are essentially three levels of vegetation, but the levels are not continuous. The lowest level is formed by coffee and ranges from 6 to 10 ft. The intermediate level is formed principally by various species of citrus and has a mean height of about 30 ft. The upper level has a mean height of about 50 ft. and is composed of the common species used for coffee shade in Puerto Rico, such as guama, guaba, capa prieto, and guaraguao. Other species of the upper level that occur infrequently include mango, jacana, and bucayo gigante.

The principal test site in Texas is near College Station in the Post Oak Savanna. It has an overstory of post and blackjack oak about 40 ft. tall. The trees are dense and the canopy relatively unbroken. Yaupon occurs as an understory that is about 15 ft. tall. The yaupon canopy was also dense and relatively unbroken. Additional research in Texas was done in stands of Macartney rose and live oak, which are much lower in stature but do have dense foliage.

Spray materials were applied from aircraft and from fixed delivery systems. Nonphytotoxic materials with dye tracers were used in the principal test sites so that the forest canopy would not be damaged. Additional spray samples were collected during applications of herbicides on other vegetation types.

The objectives of the research were to study the effects of various spray materials on (1) uniformity of spray distribution, (2) droplet-size distribution, (3) droplet population per unit area, and (4) droplet penetration through one or more forest canopies.

Experimental Techniques

Aerial application equipment.--Aerial applications with nonphytotoxic sprays were applied from an "Ag-Cat" manufactured by Grumman Aircraft Engineering Corporation. The conventional spraying system for this aircraft has a 220-gallon aluminum alloy hopper, a wind driven centrifugal pump, and 2-inch outside diameter stainless steel piping and booms. The conventional boom is mounted inside the lower wing near the leading edge. Nozzle drops of 1/8-in. alloy tubing extend below the wing.

In order to add flexibility to the spraying system, a bi-fluid system for spraying invert emulsions was installed, and a single-fluid, trailing-edge spray boom constructed for use with conventional liquids and with thickened materials sprayed through conventional nozzles. The bi-fluid modification involved mounting a 20-gallon fiberglass tank inside the conventional hopper for the oil phase of the invert, replacing the conventional pump with a bi-fluid pumping system, and mounting a trailing-edge, 2-in-1 bi-fluid boom equipped with diaphragm cutoff, bi-fluid nozzles on the aircraft.

The bi-fluid pumping system consists of two centrifugal pumps driven from a single fan through a special gearbox. The water pump is mounted directly to the bottom hopper plate with the impeller in a horizontal position. Liquid flows directly from the hopper into the water pump through a 2-1/2 in. diameter inlet port. The pump outlet connects directly to a 2-in. ball-type control valve. The oil pump is mounted on the back of a special strut-gearbox assembly with the impeller in a vertical position. Oil flows to the pump inlet through 1-in. outside diameter tubing. The pump outlet connects to a 1-in. inside diameter hose that leads to a 1-in. ball-type control valve. From the control valves, the water and oil are either recirculated to their respective tanks or directed to 2-in-1 boom where they flow through separate boom compartments to the bi-fluid nozzles. In the bi-fluid nozzles, the two fluids pass through metering orifices and into a mixing chamber where the invert emulsion is formed. Several sizes of metering orifices are available to vary the oil-water ratio. We used an oil:water ratio of 1:7. The invert emulsion in the mixing chamber then passed through the nozzle tip, which contained nine 0.041 in. diameter orifices. Thus, nine jetstreams are formed by each nozzle. Each nozzle delivered approximately 1 gallon per minute at a fluid pressure of 30 p.s.i.

When using the single-fluid spray boom for conventional liquids, thickened liquids, or particulated materials, the bi-fluid water pump was used for the material being sprayed. The oil plumbing system was adjusted to circulate diesel fuel through the pump and oil tank. Thus, the bi-fluid water pump was used to serve either the bi-fluid system or the single-fluid system.

Cableway.--The fixed system for applying nonphytotoxic sprays was located on a mountain ridge so that applications could be made from either the fixed system or from aircraft. The fixed system was a cableway on which a spray cart could traverse the same track for repeated tests.

The cableway consisted of two 5/8-in. diameter cables, with a 4-ft. vertical separation, stretched between support towers. One set of towers supported the top cable; another set the bottom cable. The cables were attached to the strain plates of the towers with turnbuckles, which were adjusted to provide the desired catenary and clearance above the forest canopy. Topography under the cableway was such that two 35-ft. towers were used at the upper end, and, 720 feet downslope, two 120-ft. towers.

A cablecart containing the spraying system was designed to ride between the two cables with two wheels above the top cable and two below the lower cable. The cart was 30 in. long, 26 in. wide, and 26 in. high. It was fabricated from 1/8- by 1-1/2- by 1-1/2-in. extruded aluminum angle and 3/8- by 3-in. aluminum bars. The spraying system consisted of a 30-ft. boom coupled to a 3-gal. spray tank through a pressure regulator and a normally open solenoid valve (fig. 11.27). Teejet nozzles were spaced at 14 in. intervals. The booms were hinged so they could be folded back for servicing from the servicing platform (fig. 11.28).

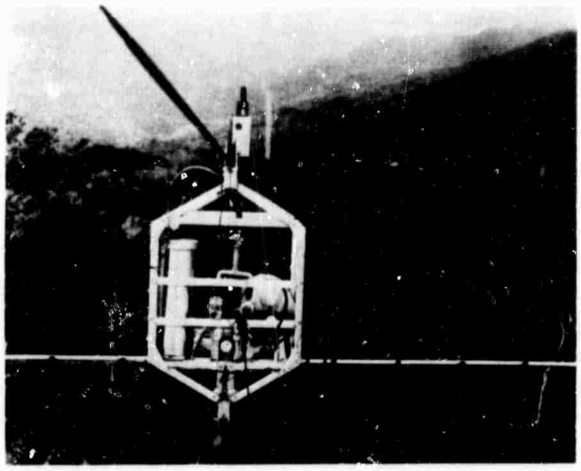

Figure 11.27.--Spray cart showing the spraying system equipped with a normally closed solenoid valve that could be actuated by radio controls or by a breakaway cable.

The cablecart was driven by an endless 1/8-in. aircraft cable, which was given three turns around a 12-in. drive drum and a 6-inch idler pulley. The drum was driven by a 2-hp., variable-speed, 220 v. d.c. motor, equipped with an electric brake. The motor was operated by an electronic variable-speed controller that rectified 240 v. a.c. supply power.

Sampling spray penetration and distribution.--A sampling station for measuring the penetration of droplets delivered from a fixed-wing aircraft was erected in a dense stand of oak-yaupon near College Station, Tex. Two 45-ft. communications towers were erected to support 105-ft. long sampling lines at three heights. The top sampling level was just above the oak canopy, 43 ft. above the ground (fig. 11.29). The middle line was below the oak but above the yaupon canopy, 16 ft. above the ground. The bottom sampling level was below the yaypon canopy, 2 ft. above the ground. Each sampling level consisted of two parallel 1/8-in. endless steel cables stretched between the towers, with 35 card-holder brackets attached on 3-ft. intervals. A cable traverse system was constructed to aid in changing the sample cards. The cables were placed in the grooves of two 5-in. diameter V-belt pulleys at each tower so that the card holder brackets could be moved to work platforms attached to one of the towers (fig. 11.30). One 4- by 4-in. kromekote card and one 4- by 4-in. polyester film sheet were attached to each bracket so

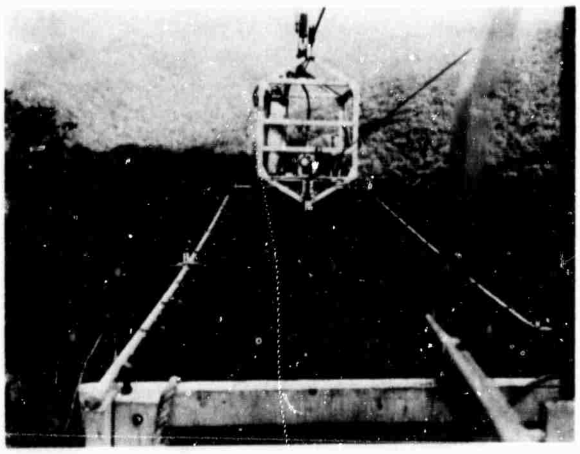

Figure 11.28.--Spray cart with booms folded for servicing.

Figure 11.29.--Top sampling level above oak canopy for intercepting spray droplets.

Figure 11.30.--Work platform for changing sample cards of the middle level--below the oak canopy but above yaupon.

that data could be obtained on drop-size distribution and volume of deposit.

Aerial spray applications were made at right angles to the sampling lines. Five 40-ft. swaths, approximately 800 ft. long, were sprayed for each test. Permanent flagging stations for guiding the aircraft were established on 40-ft. centers. The third swath passed directly over the center of the sampling lines. The aircraft flew about 75 m.p.h. about 15 ft. above the oak canopy.

Nonphytotoxic sprays containing a dye were used for all tests so that the same area could be used repeatedly. Three spray materials were tested during the course of the study: (1) Water; (2) water, table salt, and glycerine thickened to a Krebs viscosity reading of 88 with Norbak; and (3) an invert emulsion having a yield point of 150 as determined with a Mobilometer. The water and Norbak tests were applied with three types of nozzle tips mounted in No. 6135 diaphragm Teejet nozzle bodies: (1) K5 floodjet; (2) D10-45 hollow cone, and (3) D6 solid jet. The invert emulsion was applied with the bi-fluid system described previously. Nozzle angles (angle between the spray and the line of flight) of 0^{o}, 30^{o}, and 75^{o} were tested with the floodjet nozzles and 0^{o}, 30^{o}, and 60^{o} with the hollow cone, solid jet, and bi-fluid nozzles. All tests were applied at 4 gal. per acre with a pressure of 30 p.s.i.

The sampling system under the cableway consisted of four sampling stations, each with four sampling levels, oriented at right angles to the direction of spray cart travel. The four levels were (1) above the top canopy, (2) below the top canopy but above the middle canopy, (3) below the two upper canopies but above the lowest canopy, and (4) at the ground line.

Each sampling level consisted of parallel 1/8-in. diameter aircraft cables to which brackets were attached for duplicate cards. Brackets were spaced at 5-ft. intervals. The cables for the top three levels passed over wooden pulleys at each support pole and then to a takeup drum so that all card changing could be done at ground level (fig. 11.31). Brackets for the lowest level were attached to 4- by 4-in. stakes driven into the ground.

Frames were developed to support sampling plates at 2-foot horizontal intervals above and below low-growing brush. The frame consisted of two 20-ft. long probes of 1-1/4 in. aluminum tubing supported at desired sampling heights (fig. 11.32). Sheet metal trays were attached to the tubing to hold the sample plates and provide protection as the plates were pushed through dense foliage. These frames were used to measure the penetration and distribution of spray on and through brush canopies during aerial application of herbicides.

Spray deposit measurement.--Volumetric measurements of spray deposits were obtained by the colorimetric method. Dye was dissolved in the water when water alone constituted the spray liquid, or in the water portion of the

Figure 11.31.--Wooden takeup drum used to bring brackets into position so that sample cards could be changed at ground level. Another drum was located on the other end of each sampling station to reel the card-holding brackets into position.

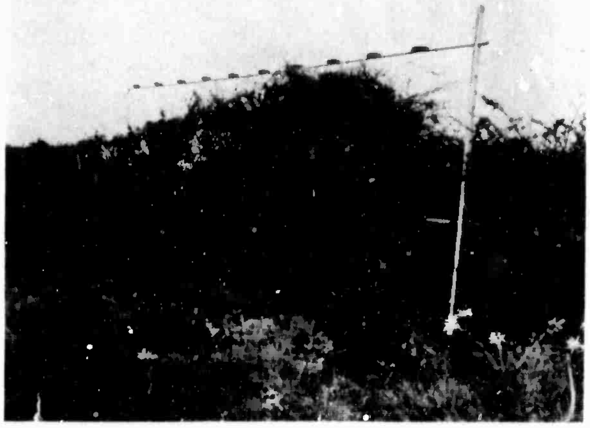

Figure 11.32.--Frame supporting sampling plates above and within a clump of Macartney rose.

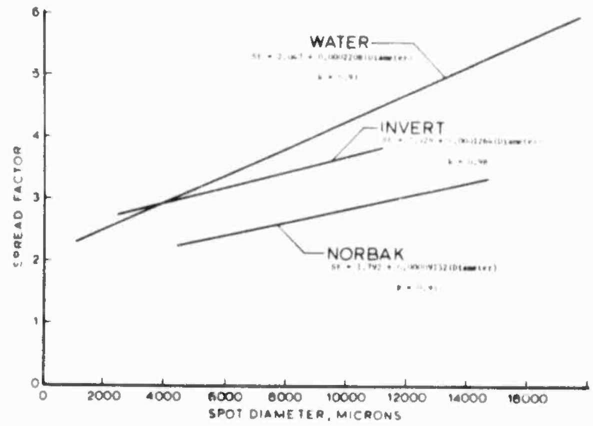

Figure 11.33.--Spread factors for various spray materials on kromekote sample cards.

mixture when various thickening agents were employed. As the spray applications were made, dyed spray deposits were collected on 4- by 4-in. square sampling surfaces. As soon as the spray droplets were deposited, the plates were placed in light-tight boxes to prevent dye deterioration and transported to the laboratory for analysis. Sample analysis consisted of dissolving the spray deposits in a measured amount of a suitable solution, either distilled water or a solution of distilled water and alcohol, and then measuring the optical density of the resulting solution with a photoelectric colorimeter. By use of Beer's Law the optical density measurements were converted to deposit per unit of sample area and expressed in terms of gallons per acre. Representative cards with a specific volume of deposit were also kept as a reference so that visual comparisons could be made.

Drop-size distribution measurement.--Samples of dyed spray drops for measuring drop-size distribution were obtained by collecting spray deposits on 4- by 4-in. square kromekote cards. The dyed spray drops produced clearly visible, well-defined stains or spots on the sampling surface. Drop-size distribution data were obtained from the spot cards by counting the number of spots in selected size classes and using appropriate experimentally determined "spread factors" to compensate for the spreading action of the droplets on the paper sampling surface and thus convert spot-size distribution data to drop-size data. Figure 11.33 shows experimentally determined spread factors for three spray materials collected on kromekote sampling cards. As illustrated, the amount of drop spread is dependent on the drop size.

Two methods were utilized in the measurement of spot-size distributions from the spot cards. Preliminary measurements and measurement of cards with low spot densities were made by enlarging the spots with a microprojector and counting with a manually operated electro-mechanical device described previously. Data obtained were placed on punched cards and analyzed with a digital computer. A more sophisticated, less time consuming, but probably somewhat less accurate method, was used for cards with higher spot densities. This involved photographing the spot cards and obtaining high contrast 35 mm. negatives which were scanned with a flying-spot-particle-analyzer. This instrument automatically relayed spot-size distribution data directly into a card-punch machine.

Test Results

Spray distribution patterns.--A limited comparison of aerial spray distribution patterns from conventional water solutions and particulated spray materials was obtained during the application of herbicides to Macartney Rose test plots near Greenlake, Tex. Both materials were applied with a fixed-wing aircraft at a calibrated delivery rate of 15 gal. per acre and a 20-ft. swath width. Twenty-seven 1/8 K 18 flooding nozzles were used on the trailing-edge boom. Dyed spray deposit samples for colorimetric analysis were collected on 33, 4- by 4-in. square stainless steel plates placed on the ground in an open area at 5-foot intervals across the plot. Coefficients of variation for the deposit measurements were computed and found to be 44.9 percent for the particulated spray and 36.4 percent for the conventional water spray. This indicates that the water spray was more uniformly distributed than the particulated spray. Plots of the distribution patterns showed more streaking (areas of high or low deposits) with the particulated material.

Additional comparisons between conventional water solutions and particulated sprays were obtained during the aerial application of herbicides to winged elm plots. These applications were made at a calibrated delivery rate of 4 gallons per acre using a 40-ft. swath width. Whirljet spray nozzles were used on the trailing-edge spray boom. Dyed spray deposit samples were collected on 50, 4- by 6-in. polyester film sample plates placed on 2-foot intervals across the plot on sample boards supported 1 ft. above ground in an open area. Two sample lines were used for each spray material. Coefficients of variation were found to be 19.3 and 30.3 percent for the water spray deposits and 47.8 and 46.1 percent for the particulated spray deposits. An additional test was conducted with particulated spray material using a 25-ft. swath width and a calibrated application rate of 6-1/2 gal. per acre. The coefficients of variation for spray deposits collected during this test were 35.4 and 41.2 percent. These results again indicated that the water spray was more uniformly distributed than the particulated material. Visual inspection of the distribution patterns supported this finding.

Comparisons between conventional (oil-in-water) emulsion and invert (water-in-oil) emulsion distribution patterns were obtained during the aerial application of herbicides to mesquite plots. A Grumman Ag-Cat spray plane equipped with the previously described bi-fluid system was used for the invert emulsion applications. The leading-edge in-wing boom equipped with 24 No. 4664-D10-45 Teejet nozzles was used to apply the conventional emulsion. Three sample lines consisting of 33, 4- by 6-inch polyester film sample collection plates spaced on 3-ft. intervals were used to collect spray distribution pattern samples in both the invert and conventional emulsion plots. The sample cards were supported approximately 1 foot above ground on special stakes. One 4- by 4-inch kromekote spot card was also attached to each sample stake to obtain data on drop population. The coefficients of variation for the invert emulsion spray deposits collected from the three sample lines were 30.4, 29.1, and 27.7 percent. Comparable coefficients of variation from the conventional emulsion samples were 24.2, 26.5, and 32.1 percent. These results indicate that the conventional emulsion spray was only slightly more uniformly distributed than the invert emulsion spray. The distribution patterns showed much more streaking with the invert emulsion; however, a higher measured application rate for the invert emulsion caused the coefficients of variation to be only slightly different. Drop-population counts from the kromekote-spot-card samples indicated that the average number of drops per square inch per gallon per acre application was 61 for the conventional emulsion and 18 for the invert emulsion.

Aerial spray distribution pattern measurements were also made in conjunction with herbicide applications to live oak plots. For this test three sample lines were spaced 10 ft. apart in an open area within a 5-acre plot. Each sample line consisted of 33 sample-holder stakes spaced on 3-ft. intervals. Two, 4- by 4-inch polyester film sheets were attached to each sample-holder stake to obtain quantitative spray deposit measurements. The Grumman Ag-Cat spray plane equipped with the conventional leading-edge in-wing boom having 24 No. 4664-D10-45 Teejet nozzles was used for the applications. Swath widths were 33 ft.

One purpose of this test was to determine the effect of leaving the polyester sample sheets exposed to sunlight for a period of time after the dyed spray was deposited. There was reason to suspect that the Carmine 2-B dye might fade, thus resulting in erroneous measurements, if the samples were not recovered and placed in light-proof boxes immediately after the spray drops had settled. It was considered that this may have been the cause of lower than expected deposit measurements in some previous studies. In order to investigate this possibility, one of the polyester film samples attached to each sample-holder stake was retrieved as soon as the spray from all swaths was deposited. The remaining sample on each stake was left exposed to a bright sun and approximately 85° F. temperature for an additional 45 min. No difference was found in the mean deposit levels from the two exposure times, indicating that dye deterioration was not a problem when the polyester sample sheets were retrieved within 45 min. Longer exposure times were not studied. The coefficients of variation were calculated for the spray deposit measurements from each of the six lines of samples and found to vary from 36.6 to 50.9 percent with a mean of 42.2 percent.

A more detailed study was made of spray distribution patterns resulting from the use of various spray materials, nozzle types, and nozzle orientations in conjunction with the study of spray penetration through a multi-story foliage canopy. The coefficients of variation were calculated for the spray deposits collected on the top sample lines during each test run.

The mean coefficients of variation from three runs of each treatment are presented in table 11.2, along with treatment mean spray deposits, the number of drops per square inch adjusted to a nominal 4-gal-per-acre application rate, the mass and numbers median diameters, and the standard deviations for the mass and numbers median diameters. The mean-spray deposits shown were determined by colorimetric analysis of dyed material collected on 4- by 4-in. polyester sheets.

The mass median diameter (MMD) is that drop diameter which divides the spray into two equal volumes with 50 percent of the volume in drops larger than the MMD and 50 percent in drops smaller. The numbers median diameter (NMD) is that diameter which divides the total number of drops equally with 50 percent of the drops larger than the NMD and 50

TABLE 11.2.--Spray distribution and drop-size comparisons

Type	Nozzle size	Angle[1]	Topline[2] deposit		Drops[3] per sq. in.	Droplet mass		Droplet number	
			Mean	Coeff. of variation		MMD	Std. Dev.	NMD	Std. Dev.
		Degrees	G.p.a.	Percent	Number	μ			
WATER									
Floodjet	K5	0	3.38	32.2	511	858	646	255	462
		30	3.47	26.4	355	947	694	278	532
		75	3.51	34.6	487	702	413	225	437
Hollow Cone	D10-45	0	3.62	27.3	318	889	617	288	557
		30	4.24	33.9	387	942	643	261	512
		60	4.01	28.6	562	913	589	329	578
Solid Jet	D6	0	5.10	40.7	35	1,383	1,181	202	507
		30	4.34	44.0	65	1,113	1,074	218	438
		60	4.43	31.3	206	730	725	123	240
NORBAK (PARTICULATED)									
Floodjet	K5	0	3.35	34.5	16	1,285	1,049	530	790
		30	3.39	38.9	24	1,435	1,109	599	841
		75	3.17	30.2	64	1,011	694	409	645
Hollow Cone	D10-45	0	5.18	33.9	25	1,098	884	441	706
		30	4.61	36.3	32	1,211	931	433	730
		60	5.09	35.4	36	1,265	853	494	827
Solid Jet	D6	0	4.16	68.0	3	3,804	2,619	385	1,312
		30	3.90	58.3	6	2,577	2,300	367	959
		60	4.89	38.8	14	1,870	1,600	285	868
INVERT EMULSION									
Bi-fluid	9-0.040	0	4.70	49.4	48	1,438	1,078	298	715
		30	4.29	42.9	46	1,403	1,191	272	581
		55	4.15	36.1	88	1,251	1,053	205	433

[1] The angle between the spray sheet and the rearward thrust line of the airplane.
[2] Mean of three test runs.
[3] Adjusted to a nominal application rate of 4 gallons per acre.

percent smaller. The MMD and NMD standard deviations were obtained from percent cumulative volume and percent cumulative numbers vs. drop-size distribution plots and represent the difference between the 15.87 and 84.13 percent cumulative levels (1 standard deviation). Figure 11.34 shows the relationship between the MMD, NMD, and their standard deviations. Figure 11.35 shows the relationship between MMD and deposit coefficient of variation and the relationship between the number of drops per square inch and deposit coefficient of variation. These curves indicate that the deposit coefficient of variation increases rapidly when the number of drops per square inch falls below 100 and also becomes larger as the MMD increases. The relationship between the median diameters and drops per square inch is shown in figure 11.36. Figure 11.37 is a graphical representation of the

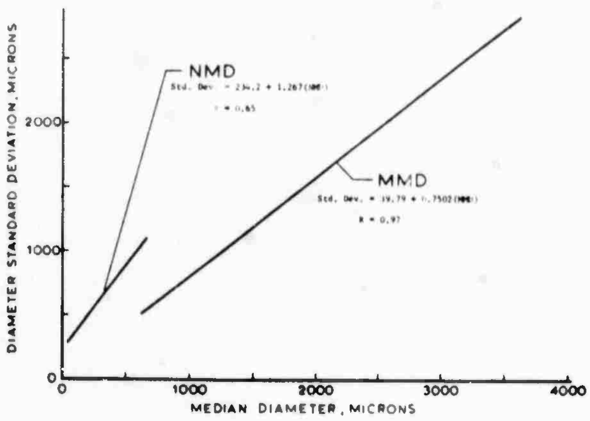

Figure 11.34.--Relationship of median diameter of spray drops to standard deviation.

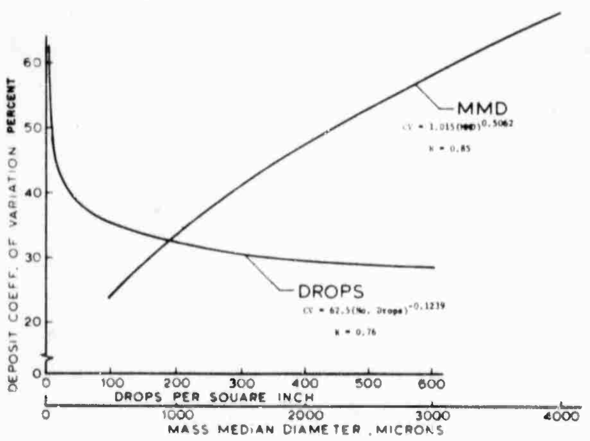

Figure 11.35.--The effect of droplet density and MMD on the deposit coefficient of variation.

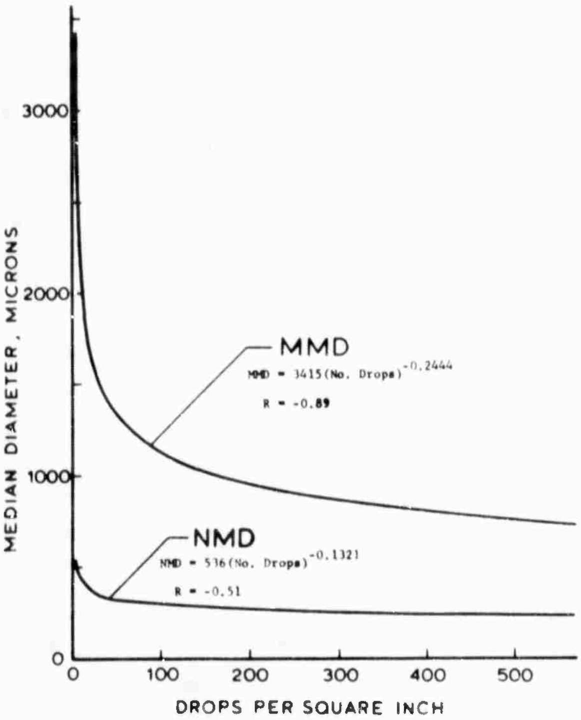

Figure 11.36.--The relationship of MMD and NMD to droplet density for an application rate of 4 gal. per acre.

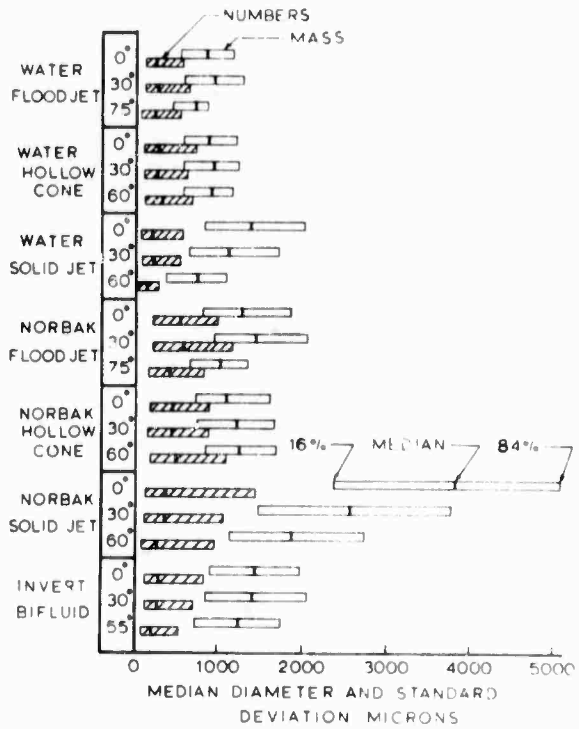

Figure 11.37.--Median diameters and drop size ranges for one standard deviation for various spray materials, nozzles, and nozzle angles.

TABLE 11.4.--Spray penetration through small trees and brush canopies

Plant species	Spray material	Volume of application	Canopy interception	Canopy penetration
		G.p.a.	- - - - - Percent	- - - - -
Macartney Rose	Norbak	15	97	3
	Water	15	93	7
Mesquite	Invert emulsion	5-3/4	54	46
	Conventional emulsion	4-1/4	40	60
Live oak	Water	4	88	12

range of median diameters and standard deviations obtained from the different orientation angles used with the various nozzles and materials. MMD was increased when the solid jet was used, particularly with the Norbak solution. Nozzle angle influenced MMD greatly for the solid jet, but only slightly for other nozzles.

Spray penetration through small trees and brush canopies.--Results from studies of spray penetration through Macartney Rose plants indicated that approximately 3 percent of the particulated spray and 7-1/2 percent of the conventional water spray penetrated through the foliage canopy (table 11.4). Samples were obtained just above the foliage and 5 ft. deep in the foliage.

Mean penetration of spray droplets through mesquite was 46 percent for the invert emulsion and 60 percent for the conventional emulsion. The upper sample lines were supported 11-1/2 ft. above ground and the lower samples 2-1/2 ft. above ground.

The mean penetration of conventional water spray through live oak plants was 12 percent. Sampling heights were 10 and 15 ft. for the upper samples and 2 ft. for the lower samples. The rather large differences in percent penetration for the different plant types reflects the relative foliage density for the three plant species.

Spray penetration through two or more canopies.--Spray penetration through two or more canopies results in additional possibilities for interception. The probility of spray droplets reaching the ground level decreases as the number of canopies or density of the canopies increases. Tests from a fixed cableway system and from aircraft indicate that the two systems provide comparable results.

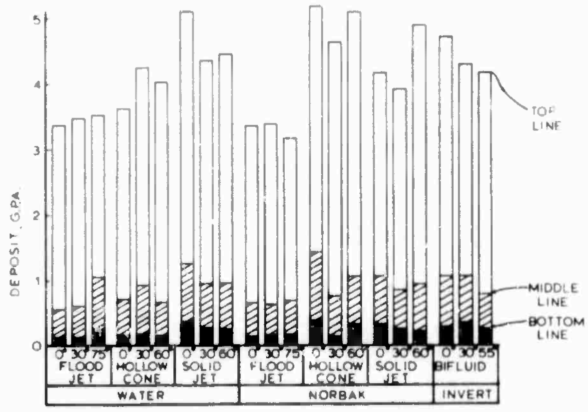

Figure 11.38.--Volume of spray deposited from aerial application of three spray materials, four nozzles, and three nozzle angles for each nozzle. The top line intercepted spray above the forest canopy, the middle line below the top canopy, and the bottom line below two canopies.

Therefore, the results obtained with the two systems will be discussed together.

The volume of spray deposited at various levels of the canopy varied with the type of spray material, the type of nozzle, and the nozzle angle (fig. 11.38). The variation of volume was not great. The causes of variation of volume deposit were more dependent on the type of nozzle than on nozzle angle or type of spray material. The lowest deposits were obtained with the flood jet nozzles for both water and Norbak. The largest deposits were obtained with the solid jet nozzle for water and with the hollow cone nozzle for Norbak. The bi-fluid nozzle also gave a large volume of spray deposit.

The volume of spray reaching lower sampling levels varied proportionately with the amount deposited on the top line above the canopy. On the average, about 21 percent of the spray volume penetrated the upper canopy and about 6 percent penetrated to the ground level. Thus, the screening effect of the vegetation was great enough so that only a small amount of spray solution was available at the ground level.

The number of droplets penetrating a forest canopy was mostly influenced by the type of spray material and type of nozzle (fig. 11.39). An adequate number of droplets was obtained with the floodjet and hollow-cone nozzles at all nozzle angles and with the solid jet nozzle at an angle of 60° with water as the spray material. A satisfactory droplet density was not obtained with any nozzle when Norbak was the spray material. Droplet density resulting from the bi-fluid nozzles was adequate for a nozzle angle of 55° but not for smaller angles.

Assuming a density of 72 droplets per square inch as being effective, the floodjet and hollow-cone nozzles provided an adequate number of droplets at the middle sampling line. Droplet density at ground level was not adequate with any nozzle or spray material.

The relationship between droplet density on the top sample line and the percentage of drops penetrating the canopies suggest that the percentage penetration remained relatively constant for drop densities greater than about 100 per square inch (fig. 11.40). Below that density the percentage penetration increased rapidly. The same relationship was shown for MMD and droplet density (fig. 11.36). One may assume, therefore, that increasing MMD results in increasing drop penetration. But the assumption is spurious because increasing MMD reduces the number of droplets. Even though a greater percentage of the large droplets penetrate a forest canopy, droplet density would be too low for adequate herbicidal effectiveness. A better compromise solution would be to accept a reduced percentage of droplet penetration, but still obtain a greater number of droplets per square inch.

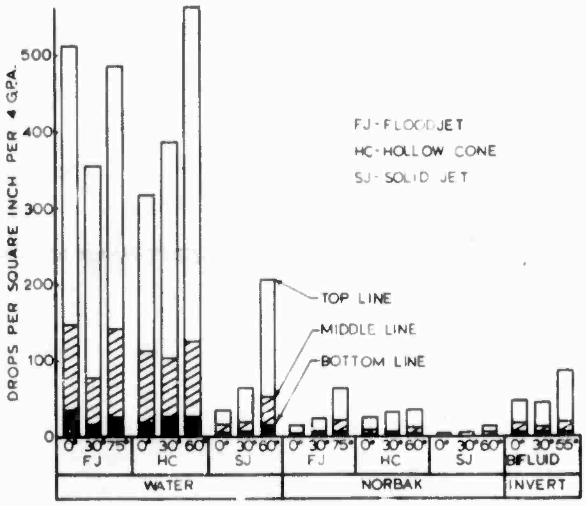

Figure 11.39.--Number of drops per square inch deposited at three levels in a two-story forest canopy.

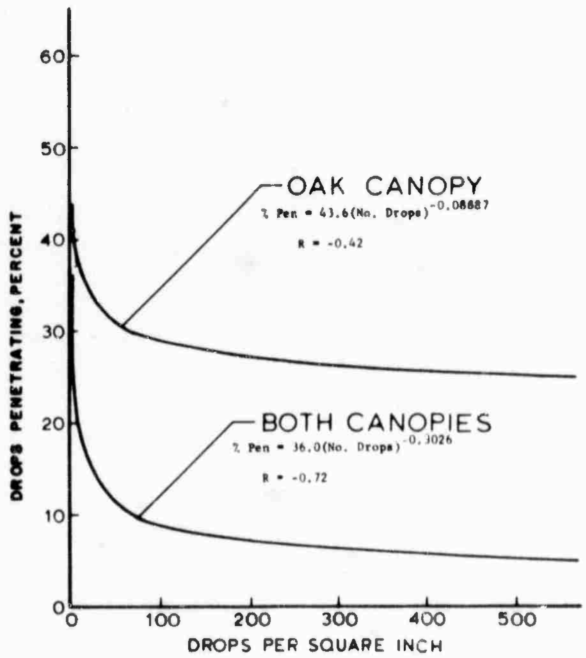

Figure 11.40.--The relation between percentage penetration and droplet density.

Conclusions

The research on spray penetration and distribution permits the following conclusions:

1. Water sprays were more uniformly distributed than were the invert emulsion or particulated sprays.

2. Floodjet and hollow cone nozzles distributed spray more uniformly than did the solid jet nozzle. Bi-fluid nozzles spraying invert emulsions produced a spray distribution similar to that of the solid jet.

3. Viscous materials produced sprays having larger MMD and NMD than did water. The standard deviations increased as MMD and NMD increased.

4. Differences in percentage penetration of forest canopies due to type of spray material or nozzle type and angle were small.

5. Percentage drop penetration decreased rapidly between droplet densities of 0 to 100 per sq. in., but remained stable thereafter.

6. The percentage drop penetration increased as MMD increased.

7. The percentage of spray penetration through forest canopies is inversely related to canopy density. Other factors such as evaporation and drift being equal, the inverse relationship is linear through the entire range of 0 to 100 percent canopy density.

APPENDIX A

Chemicals Evaluated for Defoliant and Herbicidal Activity

Common name or other designation	Chemical name
Amitrole	3-amino-1,2,4-triazole
Amitrole-T	3-amino-1,2,4-triazole:ammonium thiocyanate (1:1)
Amizine	3-amino-1,2,4-triazole:2-chloro-4,6-bis-(ethylamino)-s-triazine (1:3)
Banvel-K	2-methoxy-3,6-dichlorobenzoic acid:2,4-dichlorophenoxyacetic acid (1:2)
BMM	Mixture of borate and 3-(p-chlorophenyl)-1,1-dimethylurea
Bromacil	5-bromo-3-sec-butyl-6-methyluracil
Butynediol	2-butyne-1,4-diol
Dalapon	2,2-dichloropropionic acid
DEF	S,S,S-tributylphosphorotrithioate
Dicamba	2-methoxy-3,6-dichlorobenzoic acid
Diquat	6,7-dihydrodipyrido[1,2-a:2',1'-c]pyrazidiinium salt
Diuron	3-(3,4-dichlorophenyl)-1,1-dimethylurea
DMSO	Dimethyl sulfoxide
DSMA	Disodium methanearsonate
Dupont 767	5-bromo-3(α ethylpropyl)-6-methyl uracil
Erbon	2-(2,4,5-trichlorophenoxy)ethyl-2,2-dichloropropionate
Fenac	2,3,6-trichlorophenylacetic acid
Fenuron	3-phenyl-1,1-dimethylurea
FenuronTCA	3-phenyl-1,1-dimethylurea trichloroacetate
Folex	Tributylphosphorotrithioate
GS-14260	2-tert-butylamino-4-ethylamino-6-methylthio-s-triazine
Isocil	5-bromo-3-isopropyl-6-methyluracil
MCPA	2-methyl-4-chlorophenoxyacetic acid
MonuronTCA	3-(p-chlorophenyl)-1,1-dimethylurea trichloroacetate
M-2993	2,4,5-trichlorophenoxyacetic acid:4-amino-3,5,6-trichloropicolinic acid (4:1)
M-3060	2,4,5-trichlorophenoxyacetic acid (triisopropanolamine salts) and 4-amino-3,5,6-trichloropicolinic acid (1:1)
M-3140	2,4-dichlorophenoxyacetic acid:2,4,5-trichlorophenoxyacetic acid:4-amino-3,5,6-trichloropicolinic acid (2.15:2.15:1)
M-3151	See Orange
NIA 11092	1,1-dimethyl-3[3-(N-tert-butylcarbamyloxy)phenyl] urea
Orange	50 percent 2,4-dichlorophenoxyacetic acid and 50 percent 2,4,5-trichlorophenoxyacetic acid (n-butyl esters, 8.6 lb./gal.)
Paraquat	1,1'-dimethyl-4,4'-bipyridinium salt
Picloram	4-amino-3,5,6-trichloropicolinic acid
Potassium azide	Potassium azide
Prometone	2-methoxy-4,6-bis(isopropylamino)-s-triazine

Common name or other designation	Chemical name
Purple	50 percent 2,4-dichlorophenoxyacetic acid (*n*-butyl ester), 30 percent 2,4,5-trichlorophenoxyacetic acid (*n*-butyl ester), and 20 percent 2,4,5-trichlorophenoxyacetic acid (iso-butyl ester)
Pyriclor	2,3,5-trichloro-4-pyridinol
Silvex	2-(2,4,5-trichlorophenoxy)propionic acid
Sodium arsenite	sodium arsenite
Sodium azide	Sodium azide
Sodium chlorate	Sodium chlorate
X-77	Alkylarylpolyoxyethylene glycols, free fatty acids, and isopropanol
2,3,6-TBA	2,3,6-trichlorobenzoic acid
2,4-D	2,4-dichlorophenoxyacetic acid
2,4,5-T	2,4,5-trichlorophenoxyacetic acid

APPENDIX B

Plant Names

Common name	Botanic name
Abeyuelo	*Colubrina arborescens* (Mill.) Sarg.
Acacia amarilla	*Albizia lebbek* (L.) Benth.
Achiotillo	*Alchornea latifolia* Sw.
Agarito	*Berberis trifoliolata* Moric.
Aguacatillo	*Meliosma herbertii* Rolfe
Alelí	*Plumeria alba* L.
Allegheny chinquapin	*Castanea pumila* (L.) Mill.
Almácigo	*Bursera simaruba* (L.) Sarg.
Almendra	*Terminalia catappa* L.
American beech	*Fagus grandifolia* Ehrh.
Aquilón	*Terebraria resinosa* (Vahl) Sprague
Ash	*Fraxinus* spp.
Ausubo	*Manilkara bidentata* (A. DC.) Chev.
Baldcypress	*Taxodium distichum* (L.) Rich.
Bambú	*Bambusa vulgaris* Schrad.
Banana	*Musa* spp.
Barbasco	*Canella winterana* (L.) Gaertn.
Bayahonda	*Prosopis juliflora* (Sw.) DC.
Bitter sneezeweed	*Helenium amarum* (Raf.) H. Rock
Blackbrush	*Flourensia cernua* DC.
Blackjack Oak	*Quercus marilandica* Muenchh.
Bluestem	*Andropogon* spp.
Bristlegrass	*Setaria* spp.
Brownseed paspalm	*Paspalum plicatulum* Michx.
Bucayo gigante	*Erythrina poeppigiana* (Walp.) O. F. Cook
Buffalograss	*Buchloe dactyloides* (Nutt.) Engelm.
Burro prieto	*Capparis cynophallophora* L.
Cabbage palm	*Prestoea montana* (Graham) Nicholson

Common name	Botanic names
Cachimbo	Psychotria berteriana DC.
Cactus	Opuntia spp.
Caimitillo	Micropholis chrysophylloides Pierre
Caimitillo verde	Micropholis garciniaefolia Pierre
Calambreña	Coccoloba venosa L.
Camasey	Miconia prasina (Sw.) DC.
Camasey peludo	Heterotrichum cymosum (Wendl.) Urban
Campeche	Haematoxylon campechianum L.
Canelilla	Licaria salicifolia (Sw.) Kosterm.
Caoba dominicana	Swietenia mahagoni Jacq.
Capá blanco	Petitia domingensis Jacq.
Capá colorado	Cordia nitida Vahl
Capá prieto	Cordia alliodora (Ruiz & Pav.) Cham. ex DC.
Caracolillo	Homalium racemosum Jacq.
Carrasco	Comocladia glabra (Schultes) Spreng.
Cascarroya	Sarcomphalus reticulatus (Vahl) Urban
Catclaw	Acacia greggii Gray
Ceboruquillo	Thouinia striata Radlk.
Cedro hembra	Cedrela odorata L.
Cedro macho	Hyeronima clusioides (Tul.) Muell.-Arg.
Ceiba	Ceiba pentandra (L.) Gaertn.
Chestnut	Castanopsis spp.
Cieneguillo	Myrcia deflexa (Poir.) DC.
Cóbana negra	Stahlia monosperma (Tul.) Urban
Cojóba	Piptadenia peregrina (L.) Benth.
Common bamboo	Bambusa vulgaris Schrad.
Corcho bobo	Pisonia albida (Heimerl) Britton
Cupeíllo	Clusia krugiana Urban
Cupey	Clusia rosea Jacq.
Curly mesquite	Hilaria belangeri (Steud.) Nash
Cypress	Cupressus spp.
Douglasfir	Pseudotsuga menziesii (Mirb.) Franco
Dropseed	Sporobolus spp.
Elm	Ulmus spp.
Espino rubial	Zanthoxylum martinicense (Lam.) DC.
Fig	Ficus spp.
Gaeta	Trichilia pallida Sw.
Genogeno	Lonchocarpus domingensis (Pers.) DC.
Giant cane	Arundinaria gigantea (Walt.) Chapm.
Granadillo	Buchenavia capitata (Vahl) Eichl.
Greenbriar	Smilax spp.
Greenthread	Thelesperma spp.
Grisebach bristlegrass	Setaria grisebachii Fourn.
Guácima	Guazuma ulmifolia Lam.
Guajon	Beilschmiedia pendula (Sw.) Benth. & Hook.
Guamá	Inga fagifolia (L.) Willd.
Guano	Ochroma pyramidale Swartz ex J. St. Hilaire
Guara	Cupania americana L.
Guaraguao	Guarea guidonia (L.) Sleumer
Guava	Psidium guajava L.
Guayabota	Eugenia stahlii (Kiaersk.) Krug & Urban

Common name	Botanic name
Guayacán	*Guaiacum officinale* L.
Guayacán blanco	*Guaiacum sanctum* L.
Haya minga	*Guatteria blainii* (Griseb.) Urban
Helecho gigante	*Cyathea arborea* (L.) J. E. Smith
Hickory	*Carya* spp.
Higüerillo	*Vitex divaricata* Sw.
Hog-plum	*Colubrina texensis* (T. & G.) Gray
Hoja menuda	*Eugenia rhombea* (Berg) Krug & Urban
Honeysuckle	*Lonicera* spp.
Hueso blanco	*Linociera domingensis* (Lam.) Knobl.
Hüisache	*Acacia farnesiana* (L.) Willd.
Icaquillo	*Hirtella rugosa* Pers.
Indiangrass	*Sorghastrum* spp.
Indio	*Erythroxylon areolatum* L.
Ipomaea	*Ipomaea* spp.
Jagüilla	*Magnolia portoricensis* Bello
Juniper	*Juniperus* spp.
Jusillo	*Calycogonium squamulosum* Cogn.
Laurel avispillo	*Nectandra coriacea* (Sw.) Griseb.
Laurel geo	*Ocotea leucoxylon* (Sw.) Mez
Laurel sabino	*Magnolia splendens* Urb.
Limoncillo	*Calyptranthes krugii* Kiaersk.
Lindheimer croton	*Croton glandulosus* var. *lindheimeri* Muell. Arg.
Little bluestem	*Andropogon scoparius* Michx.
Live Oak	*Quercus virginiana* Mill.
Loblolly pine	*Pinus taeda* L.
Longleaf pine	*Pinus palustris* Mill.
Lotebush	*Condalia obtusifolia* (Hook.) Weberb.
Lovegrass	*Eragrostis* spp.
Macartney rose	*Rosa bracteata* Wendl.
Mago	*Hernandia sonora* L.
Majagua	*Hibiscus tiliaceus* L.
Mamey	*Mammea americana* L.
Mangle blanco	*Laguncularia racemosa* (L.) Gaertn. s.
Mangle botón	*Conocarpus erecta* L.
Mangle colorado	*Rhizophora mangle* L.
Mangle prieto	*Avicennia nitida* Jacq.
Maple	*Acer* spp.
María	*Calophyllum calaba* Jacq.
Maricao	*Byrsonima coriacea* (Sw.) DC.
Masa	*Tetragastris balsamifera* (Sw.) Kuntze
Mesquite	*Prosopis juliflora* (Sw.) DC.
Moca	*Andira inermis* (Sw.) HBK
Montezuma baldcypress	*Taxodium mucronatum* Ten.
Moral	*Cordia sulcata* DC.
Moralón	*Coccoloba pubescens* L.
Motillo	*Sloanea berteriana* Choisy
Muhly	*Muhlenbergia* spp.
Muñeco	*Cordia borinquensis* Urban
Negra lora	*Matayba domingensis* (DC.) Radlk.
Nemocá	*Ocotea spathulata* Mez

Common name	Botanic name
Nuez moscada	Ocotea moschata (Meisn.) Mez
Oak	Quercus spp.
Palma de coyor	Aiphanes acanthophylia (Mart.) Burret
Palma de lluvia	Gaussia attenuata (O. F. Cook) Beccari
Palma de sierra	Prestoea montana (Graham) Nicholson
Palo amargo	Rauvolfia nitida Jacq.
Palo bobo	Brunellia comocladifolia Humb. & Bonpl.
Palo colorado	Cyrilla racemiflora L.
Palo de cucubano	Guettarda scabra (L.) Vent.
Palo de gallina	Alchorneopsis portoricensis Urban
Palo de matos	Ormosia krugii Urban
Palo de pollo	Pterocarpus officinalis Jacq.
Palo de rayo	Parkinsonia aculeata L.
Panicum	Panicum spp.
Paspalum	Paspalum spp.
Péndula	Citharexylum fruticosum L.
Phillipine mahogany	Dipterocarpus spp.
Pine	Pinus spp.
Pollo	Dendropanax arboreus (L.) Decne. & Planch.
Pomarrosa	Eugenia jambos L.
Post Oak	Quercus stellata Wangh.
Pricklypear	Opuntia spp.
Rabo ratón	Casearia arborea (L. C. Rich.) Urban
Rattan	Calamus spp.
Rhodesgrass	Chloris gayana Kunth.
Roble	Tabebuia heterophylla (DC.) Britton
Sabinón	Croton poecilanthus Urban
Sandbur	Cenchrus spp.
Sanguinaria	Spondogona salicifolia (L.) House
Santa Maria	Eupatorium ordoratum L.
Sassafras	Sassafras albidum (Nutt.) Nees
Sauco cimarrón	Turpinia paniculata Vent.
Saw greenbriar	Smilax bona-nox L.
Sebucán	Cephalocereus royenii (L.) Britton & Rose
Serrasuela	Thouinia portoricensis Radlk.
Shortleaf pine	Pinus echinata Mill.
Sidecats grama	Bouteloua curtipendula (Michx.) Torr.
Slash pine	Pinus elliottii Engelm.
Sumac	Rhus spp.
Sweetbay magnolia	Magnolia virginiana L.
Tabaiba	Sapium laurocerasus Desf.
Tabonuco	Dacryodes excelsa Vahl
Tachuelo	Pictetia aculeata (Vahl) Urban
Tasajillo	Opuntia leptocaulis DC.
Tea	Amyris elemifera L.
Texas persimmon	Diospyros texana Scheele
Threeawn	Aristida spp.
Tintillo	Randia aculeata L.
Toadflax	Linaria spp.
Tortugo amarillo	Sideroxylon foetidissimum Jacq.
Tulipán africano	Spathodea campanulata Beauv.

Common name	Botanic name
Tuna de petate	Opuntia rubescens Salm-Dyck
Tupelo	Nyssa spp.
Ucar	Bucida buceras L.
Uniola	Uniola spp.
Uva de playa	Coccoloba uvifera L.
Uvilla	Coccoloba diversifolia Jacq.
Varital	Drypetes glauca Vahl
Verdiseco	Tetrazygia elaeagnoides (Sw.) DC.
Vine mesquite	Panicum obtusum HBK
Violeta	Polygala cowellii (Britton) Balke
Whitebrush	Aloysia lycioides Cham.
Winged elm	Ulmus alata Michx.
Yagrumo hembra	Cecropia peltata L.
Yagrumo macho	Didymopanax mortotoni (Aubl.) Decne. & Planch.
Yaití	Gymnanthes lucida Sw.
Yankeeweed	Eupatorium compositifolium Walt.
Yaupon	Ilex vomitoria Ait.
Wolfberry	Lycium spp.
Yello indiangrass	Sorghastrum nutans (L.) Nash
Yucca	Yucca spp.
Zarcilla	Leucaena leucocephala (Lam.) de Wit.