<u>CERTIFICATE OF SERVICE</u>

I, W. Stuart Calwell, Jr., one of the attorneys for the plaintiff, do hereby certify that I have served a copy of "Plaintiff's Response to Defendant's Request For Production of Military Personnel And Medical Records" upon counsel of record for the defendant, by hand delivering a true and exact copy thereof on the 13th day of June, 1983, to Charles M. Love, III, 1500 Commerce Square, Charleston, West Virginia.

W. STUART CALWELL, JR.

AD 824314

ASSESSMENT OF ECOLOGICAL EFFECTS OF EXTENSIVE OR REPEATED USE OF HERBICIDES

FINAL REPORT
15 August - 1 December 1967

Contract No. DAHC15-68-C-0119

MRI Project No. 3103-B

Sponsored by

Advanced Research Projects Agency
ARPA Order No. 1086

MRI

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ASSESSMENT OF ECOLOGICAL EFFECTS OF EXTENSIVE OR REPEATED USE OF HERBICIDES

by

W. B. House
L. H. Goodson
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PREFACE

This report was prepared by the Midwest Research Institute under Contract No. DAHC-15-68-C-0119 for the Advanced Research Projects Agency of the Department of Defense. The authors include William B. House, Director of Biological Sciences; Louis H. Goodson, Senior Advisor for Biology; Howard M. Gadberry, Senior Advisor for Technology; Kenneth W. Dockter, Senior Biochemist; David A. Ringle, Principal Physiologist; John C. MacFarlane, Head of the Life Sciences Section and O. B. Gerrish, Head of Food Science Section. The following consultants assisted in the writing, correction of preliminary drafts, and provided ecological perspective in the areas of their special knowledge: Dr. Boysie E. Day, Professor of Plant Physiology, and Chairman of the Department of Horticulture, University of California, Riverside, California; Dr. Norlan C. Henderson, Associate Professor of Botany and Ecology, University of Missouri at Kansas City, Missouri; and Dr. James H. Jenkins, Professor of Wildlife Management, School of Forestry, University of Georgia, Athens, Georgia.

We also wish to thank those people and their organizations whose names are shown below for their assistance in providing information for use in this report. Many of the following people contributed reprints, manuscripts, and unpublished information which were invaluable to us in assembling these data.

Although we have utilized information and the suggestions from many sources the statements, opinions and recommendations offered by the authors of this report are entirely their own and do not necessarily reflect the opinion of the Department of Defense or other government agencies.

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30 November 1967

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ABSTRACT

An information survey including published literature and personal interviews with individuals knowledgeable in the fields of herbicide usage, animal ecology and plant ecology has been conducted for the purpose of assessing the ecological consequences of extensive or repeated use of herbicides for vegetation control. The general subjects discussed in this review include (1) herbicide production, usage and trends; (2) herbicide application to crop and noncroplands, especially forests, ranges, rights-of-way, waterways, ponds, lakes and reservoirs; (3) military usage of herbicides in Vietnam; (4) acute, subacute and chronic toxicities of 21 herbicides used primarily for noncropland application; (5) persistence and elimination of herbicides from the soil (6) known ecological effects of vegetation removal by chemical methods (e.g., herbicides) and physical methods (e.g., bulldozing, fire, flooding, etc.), including both the effects on the biotic and abiotic components. Specifically, consideration is given to the effects of herbicides on wildlife, wildlife habitat, endangered species, food chains, biotic potential, plant succession, animal succession, revegetation, climate, soil erosion, laterization and related topics; (7) some conclusion regarding the ecological changes are presented; and (8) some recommendations for further ecological investigations are given.

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V. MILITARY APPLICATIONS OF HERBICIDES

Unlike civilian applications of herbicides in forestry, range management, and aquatic weed control, the development and use of herbicides for military purposes have not been adequately documented in the scientific literature. Although many post-war military herbicide investigations have been unclassified, the military technology relating to defoliants, desiccants and chemical agents for drop destruction has received little attention in the chemical, botanical, and ecological journals.

Within the past few years, a general concern has been expressed by the scientific community regarding the use of vegetation-control chemicals by the military. Therefore, in order to provide a better basis for considering the ecological consequences of various military uses of herbicides, these applications must be described in somewhat greater detail than are the civilian uses.

Information has been drawn entirely from publicly available reports, the unclassified technical literature and news accounts. The following sections represent a factual account of the background and development of military herbicides, the policies controlling the use of herbicides, and the materials and application procedures currently used in Vietnam. A brief description of the vegetation in Southeast Asia is presented along with its response to herbicidal treatment. The possible ecological consequences of these operations will be discussed separately.

Background and Historical Development of Military Herbicides

Throughout World War II, classified military research on chemical herbicides played an important role in the development of the potent selective herbicides now in world-wide use. In the search for chemical agents to destroy enemy crops, many of the key concepts of herbicidal mechanism and species selectivity were elucidated, and the effectiveness of the phenoxy herbicides as weed control agents was first demonstrated.

In late 1941, a group of prominent scientists convinced the Secretary of War, Henry Stimson, of the potential dangers from biological warfare. Stimson requested the National Academy of Sciences and the National Research Council to provide the best possible scientific advice. In response, the National Academy of Sciences established the "ABC" Committee, and, 1 February 1942, the committee's report resulted in the establishment of the War Research Service, a civilian agency with George Merck as the director.

Although a number of plant physiologists and other scientists had carried on a decade of research with plant hormones and synthetic growth-regulating agents, and many workers had noted that overdoses of plant hormones or growth regulators injure plant tissue or even kill the plants, no one had yet suggested that hormone-like agents might be useful as herbicides. Several of these research workers were destined to play pivotal roles in the development of both military herbicides and modern weed killers.[9]

These scientists included Dr. E. J. Kraus, Head of the Botany Department of the University of Chicago, who had worked extensively with growth regulators and plant hormones, and two of his doctoral students, John Mitchell and Charles Hamner, who since 1940 had both been working as plant physiologists at the USDA Plant Industry Station, Beltsville, Maryland.

Apparently, Kraus was the first to suggest that growth regulators might work as herbicides if purposefully applied to weeds in toxic doses (Peterson, 1967a). Early in 1941 he discussed this with Mitchell and Hamner, later elaborating his ideas in letters to them (Marth and Mitchell, 1944; Mitchell, 1946). Within a few months, Kraus and Mitchell began work testing various synthetic growth regulators for their herbicidal activity. In April 1942, Kraus and Mitchell learned about the work soon to be published by Zimmerman and Hitchcock (1942) of the Boyce-Thompson Institute. Zimmerman had found that the phenoxyacetic acids are exceedingly powerful growth regulators, and that one of the most potent for inducing seedless tomatoes was 2,4-dichlorophenoxyacetic acid, which was 300 times more powerful than the widely used indolebutyric acid. Without indicating the intended use, Mitchell obtained some of these chemicals, including 2,4-D, from Zimmerman and began testing a variety of compounds as herbicides in the greenhouses at the University of Chicago and Beltsville.

Kraus was sufficiently encouraged by the early results that, in late 1942, he suggested to the committees of the National Academy of Sciences that "the toxic properties of growth-regulating substances for the destruction of crops or the limitation of crop production" might be of military interest, and proposed that the herbicidal properties of these growth-regulating chemicals should be tested on field crops (Kraus and Mitchell, 1947). Because of the war, Kraus and Mitchell did not publicize the results of their 1941-1943 experiments.

[9] A thorough historical review of wartime research on herbicides, recently prepared by the Smithsonian Institution, has been published in Agricultural History, July 1967 (Peterson, 1967b). Mitchell's original 1-lb. bottle of 2,4-D is now a part of the collection in the Smithsonian's Division of Agriculture and Forest Products.

The United States Army initiated a contract with the University of Chicago in March 1943 to support the research of Kraus and Mitchell, and to pay for much of the work which had already been done. Since the war against the Japanese in the Pacific was of increasing importance, it is not surprising that the effectiveness of 2,4-D and 2,4,5-T in killing rice was included in these investigations (Kraus and Mitchell, 1947). Although the early results were promising, it was later learned that rice is generally quite resistant to 2,4-D.

Largely on the basis of the results Kraus had reported to the National Academy of Sciences, the Army intensified its herbicide research, assigning this mission to the recently established Camp Detrick (Peterson, 1967c). The Army research team carried out the synthesis and testing of nearly 1,100 substances in laboratory screening, greenhouse tests, and later under the direction of Mitchell, as applied to field crops.

Until the end of the war, the U.S. research program was an official secret. However, on January 3, 1946, Secretary of War, Robert Patterson, made public a letter from George Merck which listed, among other significant accomplishments of the wartime program, the testing of "the effects of more than 1,000 different chemical agents on living plants." Although victory was achieved before the herbicides could be used in wartime operations, Merck declared that "only the rapid ending of the war prevented field trials in an active theatre of synthetic agents that would, without injury to human or animal life, affect the growing crops and make them useless."(Merck, 1946, and Shalett, 1946)

Even though the war-time research effort was directed primarily toward anticrop agents, the investigators could foresee the considerable possibilities that 2,4-D had in agriculture. The plant industry research group at Beltsville procured 1 lb. of pure 2,4-D from the American Chemical Paint Company, and began testing 2,4-D for the control of various common weeds. These trials also included toxicity studies and animal feeding tests which established the safety of 2,4-D. To clinch this point, Kraus personally consumed 1/2 g/day for three weeks with absolutely no effect (Cohen, 1948) and (Proc., NCWCC, 1945).

During the summer of 1944, results came rapidly from a number of research groups: the selective action of 2,4-D was reported (Mitchell and Hamner, 1944); the report by Hamner and Tukey (1944) of successful control of bindweed attracted considerable public attention; and this public interest in weed killers persuaded several chemical companies to produce and market 2,4-D commercially. The following year, 1945, saw the introduction of "Weedone," the first systemic herbicide.

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Defoliants for Jungle Warfare

Nearly 20 years of research and testing were devoted to the attainment of defoliation systems capable of stripping away jungle foliage.

The record of technical development dates back to the establishment of Fort Detrick in the winter of 1942-1943. The war in the South Pacific was making new demands on military technology:

> "There was a great deal of interest at that time in destroying vegetation in the South Pacific theatre, and the principal means available was high explosives. I have forgotten how many millions of tons of high explosives were required to destroy the vegetation on some of these Pacific islands. We were asked to investigate chemicals that were available in large quantities in the United States that could be employed for 'defoliating' this vegetation." (Minarik, 1963a).

The tactical uses of chemical defoliants in counter-insurgent operations have been summarized:

> "The capability of destroying cover and concealment to defend against and fight off guerrilla and other types of tactics is absolutely essential. When we clear vegetation from roadsides, railways, and canals, we substantially reduce the opportunity for ambush, and thus allow our own operations to proceed in a more timely manner. Defoliants would also be used to demarcate boundaries. Defoliation could be used to clear gun emplacements, open up fields of fire, mark areas of bombing, or test whether or not a particular area was camouflage or actual vegetation." (Delmore, 1963)

Near the close of the war, aerial spraying of several inorganic defoliants was tested against sub-tropical vegetation in the Florida Everglades. These tests demonstrated that spray droplets applied to the forest canopy penetrated, not only the top leaves, but also the middle stratum, and some even reached the forest floor (Minarik, 1963b). Therefore, multiple treatment is not essential in stripping away tropical cover.

By June 1945, the Army was prepared to recommend the use of ammonium thiocyanate as a defoliant in the Pacific theatre. However, high Government levels decided that:

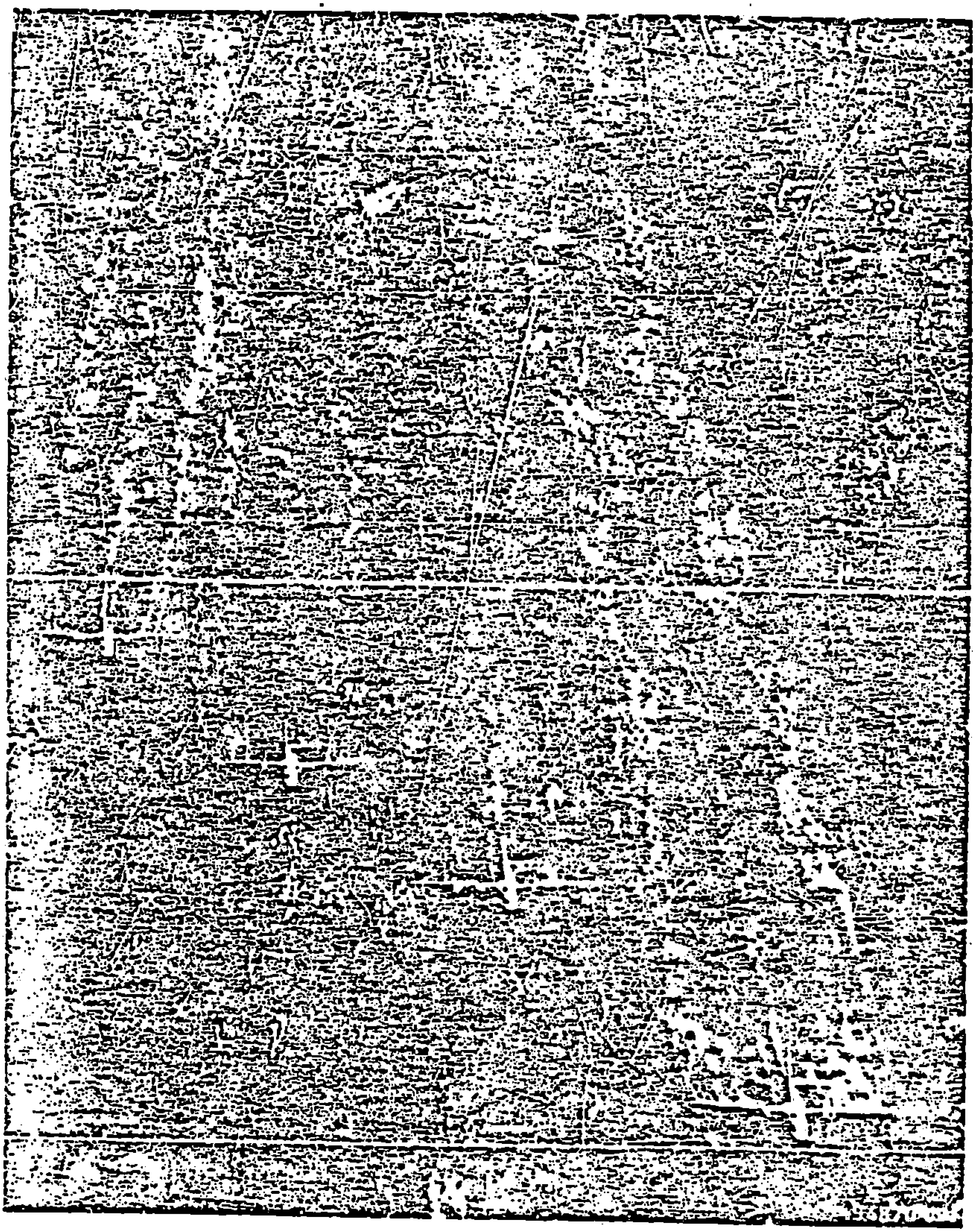


Figure V-1 - U. S. Air Force C-123 Spray Planes Defoliating Dense Forest Cover in South Vietnam

"Ammonium thiocyanate sounded very much like cyanide. which everybody knows is poisonous. If we used this chemical, we would be accused of conducting poison-gas warfare; therefore, the plan to use chemicals for destroying vegetation in the Pacific theatre was dropped. The war ended before another 'defoliant' could be developed." (Minarik, 1963a)

The chemicals used at this time are more accurately termed desiccants--agents which injure foliage by direct chemical action on contact, causing the leaves to turn brown, curl, dry up, and wither. Leaf drop by abscission may or may not occur. Since there is little absorption or translocation, only the foliage and green stems are destroyed and the rest of the plant may recover. The effect is like a heavy frost. Such agents are often termed "contact herbicides."

In a post-war program, Fort Detrick examined approximately 12,000 chemicals for defoliant and desiccant activity. The most promising 700 chemicals were screened in greenhouse and field tests for their defoliant activity (Minarik 1963b and Preston et al., 1959). Some of these defoliants were subsequently tested against tropical vegetation in Puerto Rico (Brun et al., 1961).

A highly significant demonstration of vegetation control was conducted at Camp Drum, New York, 1959. Using a mixture of undiluted butyl esters of 2,4-D and 2,4,5-T applied at 0.75 gal/acre, the trees were denuded over an area of 4 square miles (Brown, 1959).

Shortly after this successful defoliation test, the government of South Vietnam requested the U. S. Army to undertake trials of defoliants for use against guerrilla forces. This request coincided with the first announcement in the U.S. that--

"The army is experimenting with chemical techniques for stripping jungle areas of foliage to expose guerrilla fighters or other hostile forces and installations. . . .that chemical agents had already been perfected that would strip wooded areas of their foliage in about two or three days." (Raymond, 1961).

A variety of chemical agents were shipped to the Vietnamese military authorities, and from July 1961 to April 1962, a preliminary series of defoliation trials were conducted under the guidance of J. W. Brown. Even though wartime conditions interfered with the collection of detailed data, these tests established that the esters of 2,4-D and 2,4,5-T were active in killing a majority of the species encountered in Vietnam, providing the herbicide spray was properly applied to the vegetation during a period of active growth. In addition, the first aerial application of cacodylic acid showed promise as a fast-acting desiccant (Brown, 1962).

It was recommended that further screening of chemicals and development of application systems be conducted in Thailand or other tropical areas having vegetation similar to that in Vietnam.

The defoliation results were sufficiently encouraging that President Diem's government in Saigon announced on January 1, 1962, plans to use new techniques in a strong counter-offensive against communist guerrilla forces, stating:

> "Numerous techniques hitherto unseen in South Vietnam's jungle warfare are being inaugurated or are about to be used to help turn the tide of battle against the Viet Cong. One of these techniques is 'defoliation' from the air; a chemical means of stripping leaves from the foliage that hides Viet Cong movements in thickly wooded areas. Known Viet Cong bases will be surrounded by bare stretches where the guerrillas will find it difficult to move undetected from their hideouts, which are often underground." (Turnbull, 1962)

Further screening of herbicides and development of application systems have been conducted in areas of Thailand having vegetation similar to that in Vietnam. Fort Detrick directed the CONUS defoliation test program in Thailand, utilizing test sites approved by the Thai government and military authorities (Darrow, 1966a).

Concurrently, the Department of Agriculture conducted related defoliant studies for the U. S. Army at test sites in Texas and Puerto Rico (Tschirley, 1967a).

Vietnamese military forces conducted several large-scale tests in the spring of 1962. United States planes sprayed jungle growth along Highway 15, connecting the U. S. Air Force Base at Bien Hoa just outside Saigon to the seacoast city of Cap Saint Jacques. This 70-mile route had been considered unsafe for months, and government officials had to travel by air. Following this test, a high Vietnamese official said:

> "Defoliant chemicals would also be sprayed on Viet Cong plantations of manioc and sweet potatoes in the highlands. The exact locations of these plantations have already been plotted by aerial surveys. Tests have shown that manioc and sweet potatoes die four days after having been sprayed. These are the two most important food staples for the communist bands in the mountains." (Bigart, 1962)

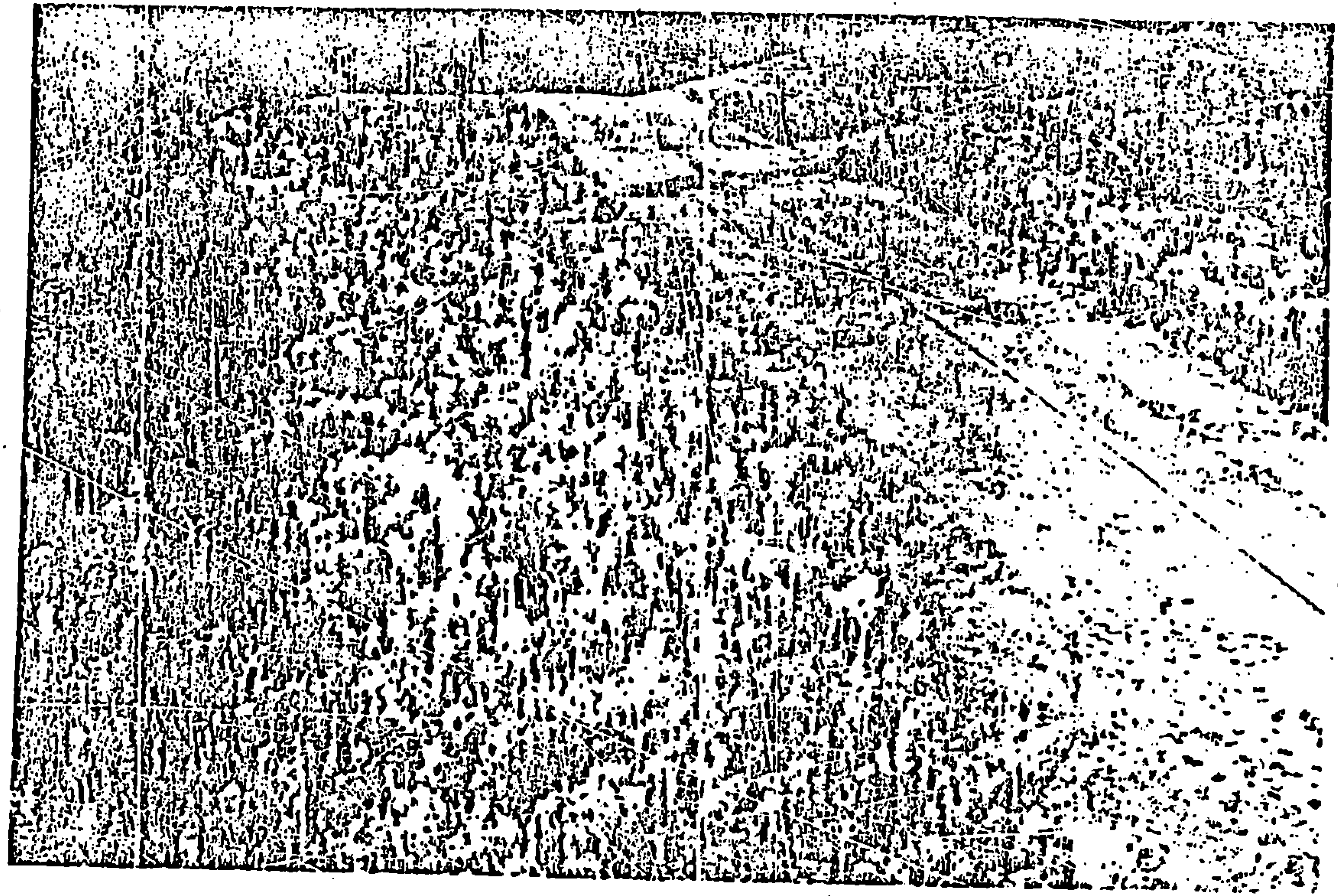


Figure V-2 - Roadside near Chon Thanh, 75 to 80 Kilometers North of Saigon. Sprayed 24 August 1961. Photo taken 16 November 1961 shows partial defoliation 300 ft back into an upland forest varying from relatively dense to open. (Courtesy U.S. Army Biological Laboratories, Ft. Detrick)

Additional defoliation tests against mangrove and nipa palm vegetation along the canals and roads of the Ca Mau Peninsula were conducted in August 1962. In these trials the heavy delta vegetation was sprayed 400 meters back from the edge of the rivers and the roads over a total length of 79 km. The herbicide formulation known as "Purple" (a brush control formulation comprising butyl esters of 2,4-D and 2,4,5-T) was applied at rates of 1.5 and 3.0 gal/acre. The mangrove vegetation responded rapidly, and was completely defoliated in about one week. Nipa palm responded slowly, turning yellow and losing its leaves; it took five weeks for these palms to fall to the ground.

Defoliation after five weeks was rated, 95% leaf drop; while the visibility of the ground from directly overhead was increased by 90% (Armed Forces Chemical Journal, 1964a, and Minarik and Bertram, 1962a).

A second important aspect of the consequences of defoliation was shown in the Ca Mau tests. Following defoliation, the mangrove stands along some of the roads became accessible to the native woodcutters, who cut the trees, converted it to charcoal and sold it for fuel (Minarik and Bertram, 1962b). Where the land was suitable after removal of the trees, various crops have been planted and cultivated (Armed Forces Chemical Journal, 1964b).

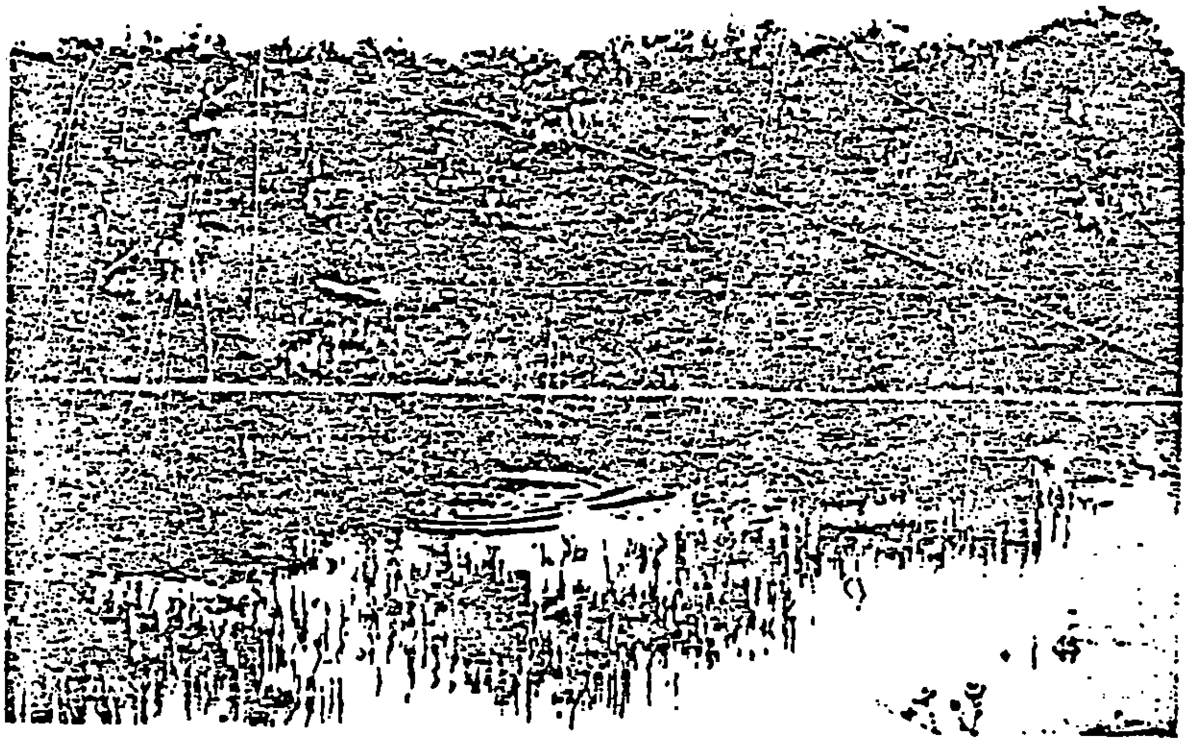
Twenty years after Kraus had first suggested them to the National Academy of Sciences, the phenoxy herbicides became a tool of war. On November 21 and 23, 1962, the Vietnamese Air Force carried out the first operational spraying of herbicides for crop destruction in known Viet Cong strongholds (Peterson, 1967d).

Current Herbicide Use in Vietnam

Since 1961, when herbicides were first used in Vietnam (Raymond, 1965, and Mohr, 1965), military defoliation has become the largest known use of herbicides. The gradually changing role of the U. S. in the Vietnam conflict has, in turn, altered both the extent and the nature of herbicide applications.

Operation Ranch Hand

Defoliation missions of the U.S. Air Force were assigned to the newly created Special Spray Flight of the 309th Aerial Commando Squadron. When the first group of huge C-123 cargo planes, specially equipped for spray application, came to Tan Son Nhut Airport on November 29, 1961, the operation, destined to be known as "Ranch Hand," began to practice a new military technology (Pruden, 1966).



Courtesy Levellyn Williams

Figure V-3 - Mangrove Swamp Woodland, Showing Uniformity of Canopy and Density of Stand

Aerial spraying of herbicides for defoliation or crop destruction cannot be directly compared with any of the civilian uses of herbicides. Even forestry spraying to suppress deciduous trees, thereby releasing conifers, represents a poor analogy. Military use of herbicides differs from other applications in several important respects--in objectives, herbicide formulations, dosage rates, and application methods; and the effects are influenced by the climate, vegetation and soils found throughout Southeast Asia. Therefore, some of the technical details of military use will be presented. These factors need to be considered before assessing the possibility of long-term ecological consequences.

Herbicide Formulations

Three basic types of herbicides are employed. The most widely used is the familiar brush killer mixture of 2,4-D and 2,4,5-T.

The chemical normally used for jungle defoliation is agent "Orange,"* a 50-50 mixture of normal butyl esters of 2,4-D and 2,4,5-T. Orange is the general purpose herbicide designed to kill foliage, with leaf fall in three to six weeks, and control persisting for seven to 12 months.

Prior to the adoption of "Orange," a closely similar interim agent known as "Purple" was employed. This formulation was a proprietary, commercial brush killer which differed from "Orange" in containing 30 percent iso-butyl ester of 2,4,5-T. Experience has shown that "Purple" and "Orange" are equivalent in defoliation effectiveness, and can be used interchangeably.

Agent "White" combines picloram with 2,4-D in a low volatility amine salt formulation. This combination provides relatively longer duration control of a wide spectrum of woody plants, plus the advantages of accurate spray placement where volatility creates problems. This agent is closely similar to compositions used for aerial spraying of power line rights-of-way throughout the U. S.

Desiccant agent, "Blue," cacodylic acid is a contact herbicide employed for rapid defoliation. This formulation does not kill many woody species, but it is an effective grass control agent, particularly useful in keeping down heavy grassy vegetation along roadsides and surrounding military encampments.

For ease of comparison, details of each composition are summarized in Table V-1.

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* The herbicides derive their colorful names from the color-coded paint stripe which girdles each shipping drum.

TABLE V-1

COMPOSITION AND CHARACTERISTICS OF MILITARY HERBICIDES

Agent	Composition		Lb/Gal AE	Purpose
Orange	n-Butyl ester 2,4-D	50% (wt)	4.2	General defoliation
	n-Butyl ester 2,4,5-T	50% (wt)	3.7	Forest
		Total	8.9	Brush
				Broad-leafed crops
Purple	n-Butyl ester 2,4-D	50% (wt)	4.2	General defoliation
	n-Butyl ester 2,4,5-T	30% (wt)	2.2	Interim agent used
	Isobutyl ester 2,4,5-T	20% (wt)	1.5	Interchangably with
		Total	8.9	Orange
White (Tordon 101)	Tri-isopropanolamine salt 2,4-D		2.0	Forest defoliation
	Tri-isopropanolamine salt picloram		0.54	Long-term jungle control
		Total	2.54	Brush suppression
Blue (Phytar 560-G)	Sodium cacodylate	27.7%		Rapid defoliation (short duration)
	Free cacodylic acid	4.8%		
	Water; sodium chloride	bal.	3.1	Grassy plant control
				Rice destruction

Herbicidal action of the "Orange" and "White" formulations depends upon absorption by the plant tissue and translocation throughout the plants. Properly applied, in sufficient doses, this systemic effect can kill plants, and prevent root sprouting in all but the largest and most resistant trees.

Cacodylic acid or "Blue" does not depend upon translocation or systemic action. This organic arsenical compound (dimethylarsenic acid) acts much like the closely related arsenical crabgrass killer MSMA (monosodium methane arsonate) used on lawns. Both compounds are highly effective killers of certain grass plants. Cacodylic acid was originally intended for the control of Imperata, elephant grass, bamboo and other plants of the grass family in defoliation operations (Beecher, 1966). However, the early defoliation trials in Vietnam showed that cacodylic acid was a fast-acting contact desiccant capable of withering vegetation within a few days (Brown, 1962b). When applied to foliage in high concentrations, cacodylic acid destroys the leaf before appreciable translocation can take place. When applied at lower rates, absorption and translocation throughout the plant are possible. It is used on rice fields in enemy controlled country, where it destroys existing crops but does not affect subsequent growths (Lucas, 1967).

In most civilian applications of herbicides, the weed killers are diluted in oil or water as a carrier, or are emulsified as normal or as invert emulsions. For military applications, however, the "Orange" and "Purple" agents are sprayed undiluted. Many years of experience in aerial application of herbicides in the U. S. have shown that the ester formulations generally achieve better control of the treated vegetation than can be obtained with amine salts and other formulations.

Application Factors

The spray equipment used in Vietnam, as well as the application parameters, are significantly different from what is used in other herbicide spraying operations.

Both fixed-wing and helicopter applications have been made. The HU-1B helicopter has been made available to the U.S. Army and to the Vietnamese Air Force (R.V.N.A.F.) for special types of herbicide applications.

The basic spray plane, however, is the twin engine C-123 aircraft, equipped with a chemical tank of 1,000-gal capacity and A/A45y-1 internal defoliation dispensers (Farm Chemicals, 1966a). Each plane is fitted with two wing booms and a tail boom, using 14 nozzles on each wing boom and eight on the tail boom. All spray operations are controlled from a console located in the back of the plane, designed to insure uniform flow and accurate rates of spray application. The normal crew complement consists of pilot, co-pilot,

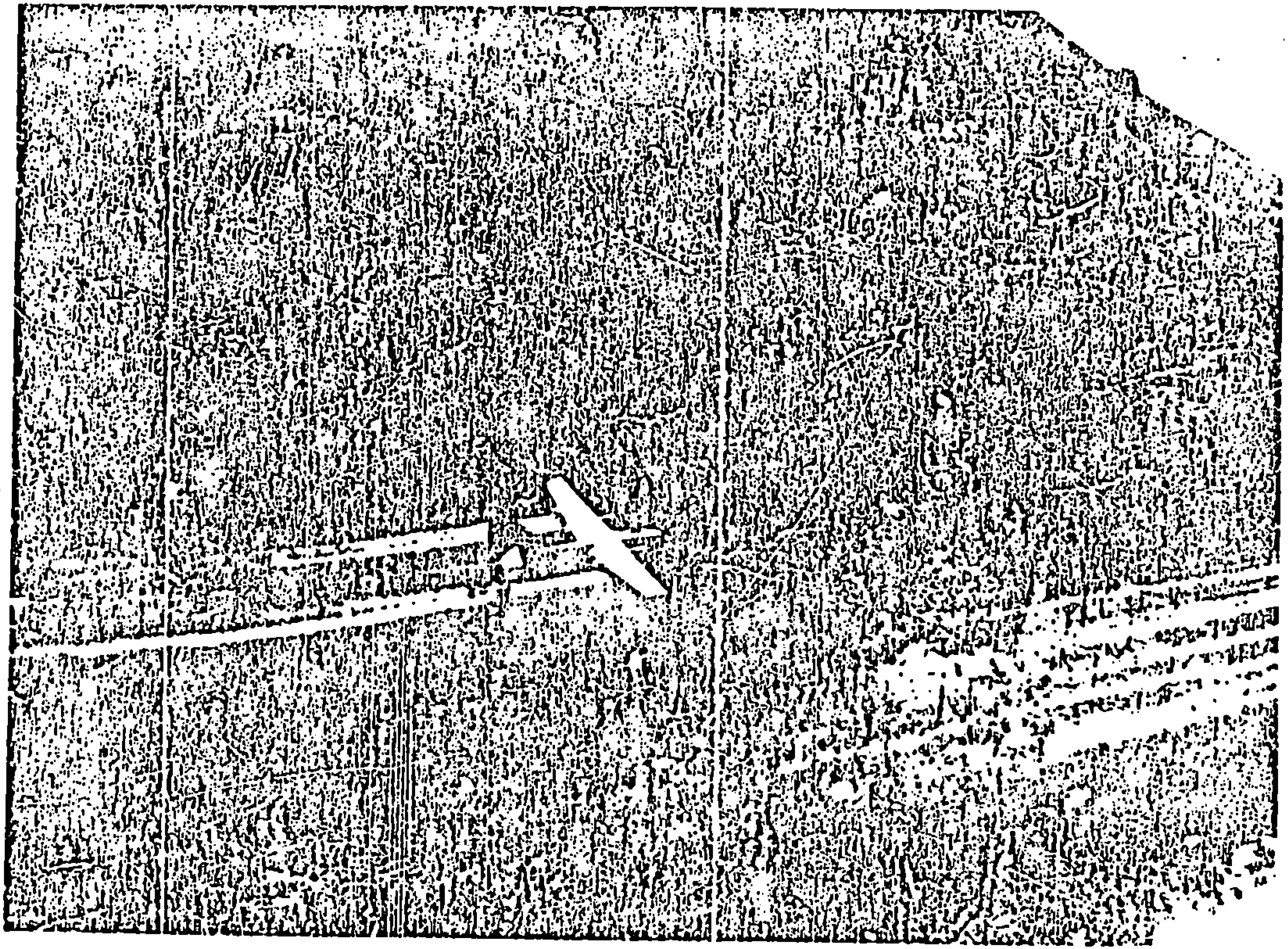


Figure V-4 - Ranch Hand Planes at Tree-Top Height Clear Strips through Viet Cong Strongholds to Disclose Ground Activity. Low level application in still morning air helps minimize drift and provides maximum reduction in obscuration. (Courtesy U.S. Army Biological Laboratories, Ft. Detrick) and a technical specialist who operates the spray console. The spray equipment is calibrated to discharge the 1,000-gal tank in a 5-min period; however, the tank can be emptied in 30 sec in case of emergency.

Like aerial spraying for civilian applications, the spray run is made as close to the foliage as practical, and at a relatively low speed. The forests of Vietnam have a canopy which generally reaches up to 90 ft, with occasional trees towering to about 125 ft. The normal altitude for spray application is 150 ft. Speed is maintained at 130 knots, only 7 knots above stall speed (Lucas, 1967). Under these conditions, the spray emerging from the open nozzles is atomized by air turbulence to produce herbicide droplets ranging from 100 to 400 μ in diameter with an average drop size of about 300 μ. The spray mist settles onto the forest canopy in a swath approximately 250 ft wide.

Weather, wind and thermal currents greatly influence the effectiveness of the herbicidal spray. The most effective spray results are obtained in the early morning when the wind is calm and the spray can settle directly onto the target (Lucas, 1967).

Tests have been made to determine the degree of spray-droplet interception by the canopy, and by the intermediate and lower stories in the forest (Tschirley, 1967b). In a moist tropical forest, approximately 80% of the spray droplets are intercepted by the foliage of the topmost canopy; 14% caught by the intermediate levels of vegetation; and only 6% of the total spray application reaches the ground level plants. Data on penetration achieved with several different types on spray booms is contained in the Appendix, Figure A-2 (p.300).

Spray drift is an important factor which influences the effectiveness of herbicide applications. Many fine droplets (200 μ or less) are formed when liquid is released from aircraft. These small drops are markedly affected by air currents. For example, a 200 μ droplet will drift 9 ft while falling 20 ft in a lateral airflow of 1 mph. (Tschirley et al., 1967). The farther above the jungle canopy the spray is released, the more drift will occur.

Some drifting of small droplets occurs under almost all conditions. Calibration tests conducted in Thialand established that it is necessary to release about 20% more herbicide than will be deposited onto the jungle vegetation. For example, a specified treatment with 100% "Purple" at 2.0 gal/acre deposit volume required release of 2.5 gal/acre from the aircraft, giving a recovery of 80% (Darrow et al., 1960). The 20% not deposited on the test cards used in calibration can be ascribed to a combination of drift and evaporation.

Air turbulence resulting from low flying aircraft is an important factor in providing distribution of spray throughout the vegetative profile.

When all droplets are falling in a straight line, most of them will be intercepted by the upper portions of the forest canopy. Turbulence from the aircraft helps to distribute the droplets throughout the foliage. The number of drops deposited per square inch of leaf surface has a striking effect on the response of herbicides. Behrens (1957) found that the effectiveness of 2,4,5-T increased greatly as the number of droplets per square inch increased from nine to 72, while the total amount of 2,4,5-T remained constant.

The picloram and cacodylic acid formulations are considered non-volatile, and thus are subject only to wind drift of fine droplets. The n-butyl esters of 2,4-D and 2,4,5-T, on the other hand, exhibit appreciable volatility under both laboratory and field conditions (King, 1966, Adams et al., 1964, Vernetti and Freed, 1964, and Miller, at al., 1964). Specialists point out that even so-called low volatile esters of the chlorophenoxy acids will exhibit measurable volatility when sprayed at the temperatures prevailing in Vietnam. Thus it seems clear that herbicide vapors are formed when "Orange" or "Purple" are sprayed. In fact some of the effectiveness of these formulations in penetrating and defoliating heavy jungle vegetation has been ascribed in part to the vapors (Farm Chemicals, 1966).

Drift damage is usually minimized by allowing a suitable buffer zone. However, accidents have occurred. There are reports of sensitive vegetation, such as rubber trees or cotton, being damaged nearly 15 miles from the point of spray release (Face, 1963).

Defoliation Targets and Objectives

Military considerations dictate how and where herbicides will be applied--factors greatly influencing the severity and permanence of ecological disturbance. The particular tactical objectives largely determine the type of vegetation treated, as well as whether temporary leaf drop or plant kill is obtained. Policies regarding target selection influence the geographic distribution of where the spraying is done, and the extent of the area covered by herbicide application.

The rate and nature of revegetation and succession largely depend on whether isolated strips and patches of jungle vegetation are destroyed, or whether large contiguous areas are controlled. Spraying cropland gives different ecological effects from those created by the defoliation of relatively undisturbed forest.

Aerial defoliation is carried on against vegetation which includes water weeds in the Mekong Delta, the multi-storied tropical rain forests, second-growth brush and grasses along communication routes, and mixed deciduous or semi-evergreen forests in mountain regions. Depending on the military objectives sought, herbicides are selected to produce short-term defoliation or long-term plant kill. The following list enumerates some of the major defoliation targets.

* Nipa palm and mangrove woodlands grow in coastal areas in deltas and within reach of tidal waters along the banks and out into the rivers and canals of South Vietnam. The edges of these waterways are sprayed for a distance of 200 to 800 meters back from the water (Minarik and Bertram, 1962c). Since these are permanent traffic routes, the objectives include total plant kill and long-term vegetation control. Respraying at yearly intervals is generally required.

* Rain or Moist Evergreen forests usually have three stories of foliage with a ground cover of shrubs, vines, and herbs of variable density. These targets are sprayed to create bare stretches surrounding Viet Cong strongholds so that movement of men or supplies in and out of the area can be observed from the air (Trumbull, 1962). This type of target requires rapid defoliation; however, long-term control or permanent kill is not essential.

* The dense shrubbery and second-growth brush along highways and supply roads create cover for ambush. These areas are defoliated back into the edge of the forest to deprive the Viet Cong of concealment (New York Times, March 10, 1966, Raymond, 1965, and Pruden, 1966). At points where Viet Cong are known to have set up road blocks for the confiscation of "taxes," an area 400 meters in extent is cleared to expose such operations for aerial reconnaissance and attack.

* In the Mekong Delta area, the Viet Cong often secrete caches of ammunition, food and supplies, so well concealed that they are difficult to find on the ground and impossible to detect from the air. Trees, weeds and underbrush are defoliated to disclose the location of these supply dumps.

* In areas that have been cleared for villages, buildings and military posts, heavy grasses and foliage may hide the infiltration of unseen attackers. This foliage is treated to hold down the grasses and foliage out to a safe distance. Long-term control is desirable in this application.

* Upland forests comprise mixed deciduous and semi-evergreen stands representing some of the heaviest forest canopies in Vietnam. Pathways and trails are defoliated between villages of the primitive mountain people and nearby Civil Guard defense units (Bigart, 1962). The same type of forest is typically found along the infiltration routes and supply trails just south of the Demilitarized Zone (New York Times, September 24 and 27, 1966). These areas are stripped to disclose troop and supply movements to aerial reconnaissance.

* A continuing struggle has been made to keep the National Rail Lines operating in spite of the fact that guerrilla bands have cut the line at numerous points by the demolition of bridges (Pruden, 1966). To minimize the opportunity for sabotage, the edges of the forest are treated at sufficiently frequent intervals to control foliage that would obscure guerrilla activity from the air.

* The mountain forests of the Annamite Chain hide the paths of supply trails from North Vietnam, through Cambodia and Laos into South Vietnam. Strategic points along both the Sihanouk and the Ho Chi Minh trails in Laos have been liberally sprayed (Foisie, 1966, and New York Times, May 19, 1966), presumably with the knowledge and cooperation of the Laotian Government (New York Times, May 19, 1966).

* The most recent and massive defoliation effort is now under way in the southern portion of the Demilitarized Zone (Bloomington Daily Herald, October 2, 1966, and New York Times, September 27, 1966) which contains some of the most dense forest vegetation in all Vietnam (Lucas, 1967). The DMZ, a 6-mile-wide zone extending 55 miles from the Gulf of Tonkin to the mountainous inland border has been sprayed for the last few months with hundreds of tons of herbicide (Washington Daily News, February 6, 1967). The lower 4 miles of the DMZ is scheduled for herbicidal treatment as well as mechanical removal where necessary (New York Times, September 23 and October 2, 1966).

* South Vietnamese crops have been destroyed with herbicides to deny food to the guerrillas (New York Times, March 10, 1966). Relatively few details about crop destruction missions are available. Crops said to have been damaged since spraying first began in 1962 (Pace, 1966, and New York Times, January 12, 1962), include: Manioc and sweet potatoes (Bigart, 1962), rice, sugar cane and vegetables (Pruden, 1966).

The selection and scheduling of targets for jungle defoliation or for crop-destruction missions involve a complex chain of military decisions and political review designed to achieve maximum effectiveness, as well as minimize the risk of unfortunate errors in herbicide spraying. These procedures have been described by Wesley Pruden, Jr. (1966).

> "Setting up targets is a ticklish diplomatic business. Nominations are made by either U.S. or Vietnamese army commanders, but if an American officer wants a target sprayed, he has to pass the recommendation on to a Vietnamese officer, who goes over the target with the province chief. Then the recommendation goes to the Vietnamese army's general staff in Saigon and, if approved, the request is sent on to the intelligence section of the U.S. Military Assistance Command - Vietnam, in Saigon."

Finally, if it clears all these desks, the request goes to the U.S. Ambassador in Saigon. Occasionally, an especially ticklish request goes all the way to Washington. One recent example involved General Westmoreland's request to begin defoliation of the DMZ, which was submitted to Washington for approval (New York Times, October 2, 1966).

In spite of all precautions, occasionally some spray may drift from a target area, causing damage to rice crops or rubber trees. When claims are made, prompt action is taken to pay damages. The current price for a mature rubber tree is $87 (Beecher, 1966).

Even more stringent procedures are used to limit crop-destruction missions to those specific areas where military effect will be greatest. Charles Mohr (December 1965) reported:

> "There is a complex system of political and military controls on the crop-destruction program. The program which began last spring has touched only a small fraction--50,000 to 75,000 acres--of the more than 8 million acres of cultivated land in South Vietnam. This is the intention of policy-makers.
>
> "Although the Viet Cong control or at least contest 70% of the land area of the nation, crop-destruction missions are aimed only at relatively small areas of major military importance, where the guerrillas grow their own food or where the population is willingly committed to their cause.
>
> "Officials say that no herbicide missions have been flown or will be flown in heavily populated areas. There has been no crop destruction, for example, in the Mekong Delta.

"There is concern that any attempt to destroy crops in heavily populated areas dominated by the Viet Cong could only send a new flood of displaced Vietnamese to join South-Vietnam's 730,000 refugees.

"It is also suggested that unless the herbicides were applied on a vast scale, a move that would probably be politically impermissible, it could have little effect in heavily populated areas. 'There is just so much food in the Delta that crop-destruction missions here would have no real military value,' one official said.

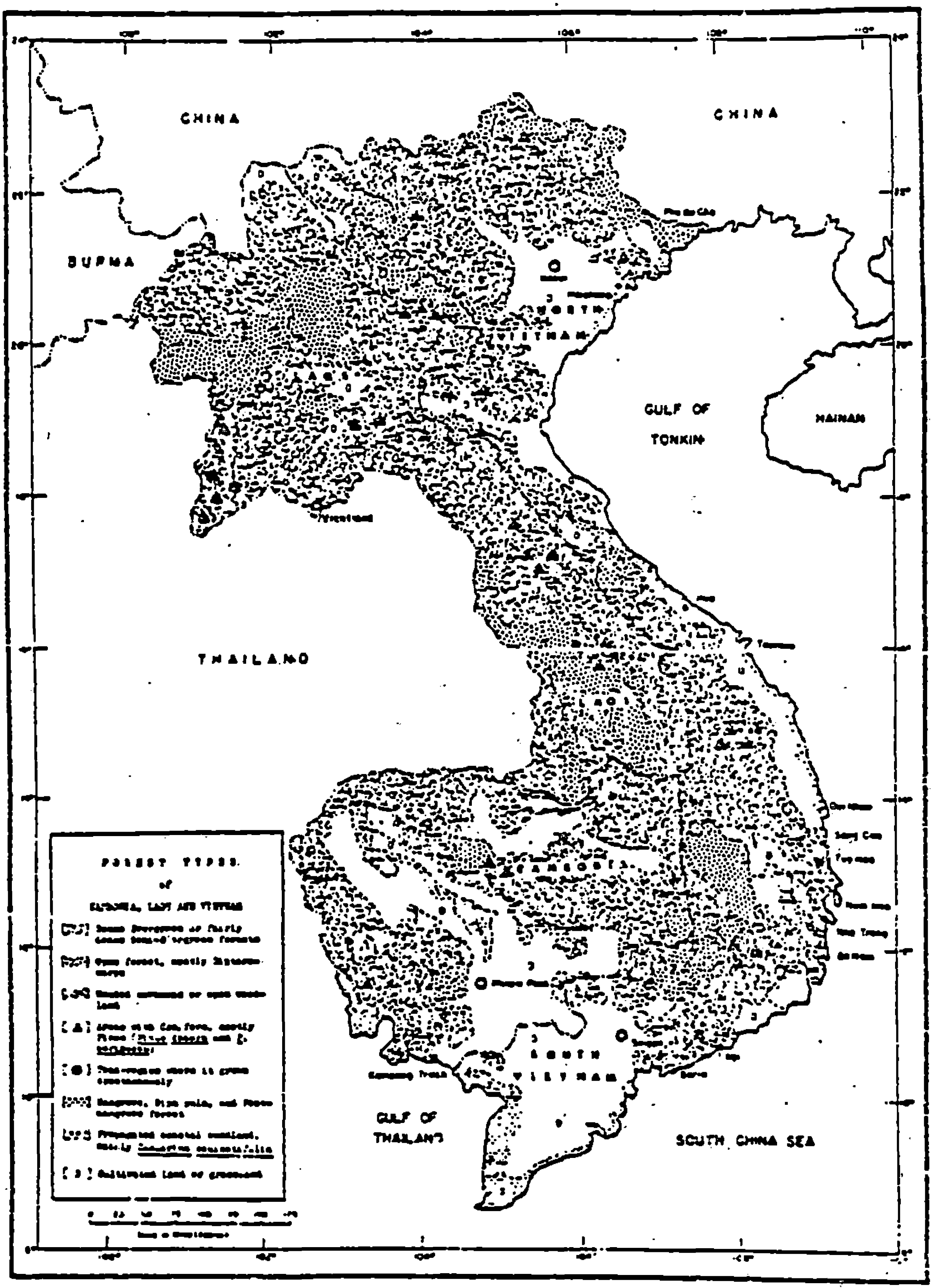
"Destruction operations are intended primarily for food fields in such Viet Cong base areas as War Zone D, north of Saigon, and in areas where growers are considered willing Viet Cong supporters.

"Some Viet Cong units are devoting as much as 50% of their manpower to growing food. . . .food shortages have become so acute in central Vietnam that some analysts expect the enemy to shift more of its military activity toward the North Vietnamese border, to ease the supply of provisions."(Pace, 1966)

Major Vegetation Types of Southeast Asia

The overall plant formations of Southeast Asia, and in particular the forests in Thailand and Vietnam, have been extensively studied and well documented in the botanical and forestry literature (Lecompte, 1907-1938, and Richards, 1952). Extensive investigations were first conducted by the French botanists and foresters (Chevalier, 1913 and 1929, Maurand, 1943). More recent studies of the vegetation in the area of the Mekong Delta (Duke, 1963, Van Cuong, 1960, and Duke, 1961, and the forests of Vietnam in general have been undertaken by specialists of the United States (Kernan, 1964). The most comprehensive of these recent investigations are "Vegetation of Southeast Asia: Studies of Forest-Types, 1963-1965" by Llewelyn Williams (1965), and "Forests of Southeast Asia, Puerto Rico and Texas" (Williams, 1967). The map (Figure V-5) from Williams' report shows the extent and distribution of various forest types in Vietnam and adjoining regions.

According to publications issued by French botanists, there are more than 1,500 species of woody plants in Vietnam, varying in size from small shrubs to large trees; hard-stemmed reeds to bamboos; and a wide variety of species of



Courtesy Lewellyn Williams

Figure V-5 - Major Forest and Vegetation Types in Southeast Asia palms, woody vines or lianes, and herbaceous plants. The major forest formations occurring in Vietnam include the following:

1. Evergreen, Broad-leaved Rain or Moist forests. Rain forest occurs in areas where the annual rainfall exceeds 100 in., is well distributed throughout most of the year, and with only a short dry period. True Rain forest is rather limited in distribution, being confined mainly to lower and middle elevations on mountain slopes. Evergreen Moist forest is found in areas where there are well defined wet and dry seasons of about equal length, and influenced by the monsoon climate.

2. Dipterocarp forest, probably the most extensive type, covering up to about 50% of the total forested area of Vietnam and neighboring countries.

3. Mixed Deciduous forest, usually heavily cut over and rather open.

4. Dry Evergreen forest, concentrated especially along river or stream banks.

5. Montane forest, containing oak frequently mixed with conifers, at middle and upper elevations.

6. Coniferous forest, in which species of pine (Pinus) form rather extensive stands in the uplands.

7. Swamp forests:

a. Mangrove woodland, in coastal areas, especially in deltas and around river estuaries.

b. Stands of nipa palm, also in deltas and tidal reaches, usually where mangrove occurs.

c. Stands of cajeput (Melaleuca), in brackish water along the inner border or in the vicinity of mangrove.

d. Fresh water swamps, generally in the interior.

8. Savannas, either open or sparsely wooded, and dominated by a ground cover of coarse grasses.

9. Thorn woodland, consisting of shrubs and small to medium-sized trees, many of which are armed with sharp spines, and often mixed with bamboo to form a tangle difficult to penetrate.

10. Bamboo brakes, frequently forming dense fringes along banks of streams and rivers, and develop rapidly in abandoned tilled land or when clearings are made in most types of forests.

Some of the forest associations in Vietnam, as in adjacent countries, are extremely complex in their floristic composition. The tallest (up to 100 ft or more), most dense and complicated type is an undisturbed Rain forest which, in some instances, may contain in an area of one acre up to 150 or more species of shrubs and small to large trees. Stands separated by only a short distance may show strikingly different features, particularly in their structure and the species present, so that their classification is oftentimes different. This diversity of forest composition in Vietnam, as in other tropical regions, may be ascribed to the variability of environmental conditions, influenced by climate, soil, drainage, and by human interference. The last named factor is in the form of felling for timber, routine burning, and the long established system of slash and burn or shifting agriculture, widely practiced especially by people inhabiting remote or mountainous areas in the interior.

Variability in floristic composition is shown in Table V-2, which inventories the principal species appearing in three strata or stories forming a Dry Evergreen forest, located on two test sites treated with herbicides in Thailand (Darrow et al., 1966). The two sites are situated in close proximity, one on the east side of the Pranburi River in the upper Peninsula, the other on the west side. It will be noted that Site I is nearly devoid of a ground layer of shrub growth. Site II, however, has a dense undergrowth, representing approximately 15% of the plants tallied. The following records, extracted from Williams' recent study, are especially pertinent to any ecological studies of the effects of herbicides and desiccants on the vegetation of this type of forest.

> "Forests of South Vietnam: The forests of South Vietnam have been devastated for many centuries. First nomadic or semi-savage people occupied the land and destroyed the forests without discrimination. After that came the Annamites who, in spite of a more advanced civilization, regarded the forest as capable of regenerating itself indefinitely, and gave no thought to its protection. Despite ample rainfall and other favorable conditions for growth, the forests were unable to re-establish themselves after prolonged periods of destruction. As a result, much of the vegetation that formerly covered Cochin-China, now forming southern South Vietnam, consists in the main of secondary growth, interspersed with scattered stands of primary forests.

Courtesy Llewelyn Williams

Figure V-6 - Rain Forest in the Mountains of Southeast Asia. "Khanun-nok" (Palaquium obovatum, is characteristic of moist tropical upland forests.

TABLE V-2

PERCENT COMPOSITION AND FREQUENCY OF PRINCIPAL WOODY SPECIES IN THE DOMINANT, INTERMEDIATE, AND SHRUB LAYERS OF TEST SITES I AND II

Species	Test Site I Composition (%)	Test Site I Frequency	Test Site II Composition (%)	Test Site II Frequency
Dominant Layer				
Lagerstroemia floribunda	0.2	84	4.3	96
Mansonia gagei	4.6	95	0.4	37
Diospyros coaetanae	0.7	81	1.[illegible]	68
Millettia leucantha	+a/	75	+	27
Dialium indum	+	23	0.9	74
Antheroporum pierrei	1.9	72	+	6
Diospyros mollis	+	67	+	46
Lagerstroemia loudonii	0.3	66	+	34
Spondias mangifera	+	35	+	66
Manilkara hexandra	0.6	61	+	39
Diospyros curranii	+	49	+	39
Garuga pinnata	+	37	0.5	47
Bambusa arundinacea	-b/	-	9.0	37
Grewia elatostemoides	+	+	1.5	29
Subtotal: composition	8.3		18.4	
Intermediate Layer				
Streblus zeylanica	45.0	100	9.5	22
Cleistanthus dasyphyllus	28.0	95	0.4	21
Celtis collinsae	0.7	92	0.2	40
Hydnocarpus ilicifolius	0.4	31	4.3	80
Vitex quinata	0.3	50	2.8	80
Atalantia spinosa	0.6	77	0.4	35
Diospyros cauliflora	1.2	75	+	45
Euphorbia trigona	3.2	75	0.6	24
Phyllanthus sp.	+	71	2.2	59
Niebuhria siamensis	+	48	+	72
Memecylon ovatum	6.9	66	12.1	48
Grewia tomentosa	+	18	3.4	66
Mitrephora keithii	0.9	64	+	2
Sindora maritima	+	5	0.6	62
Olea maritima	0.5	18	3.6	37
Phyllanthus emblica	+	3	0.6	27
Subtotal: composition	87.7		40.7	

TABLE V-2 (Concluded)

Species	Test Site I Composition (%)	Test Site I Frequency	Test Site II Composition (%)	Test Site II Frequency
Shrub Layer				
Cleistanthus sp.	+	19	16.2	95
Acacia comosa	+	46	14.5	91
Mezoneurum enneaphyllum	+	33	+	91
Capparis thorelii	+	38	0.7	90
Ventilago calyculata	0.3	97	+	55
Hymenopyramis brachiata	+	27	3.2	83
Zizyphus oenoplia	+	20	+	54
Sphenodesma pentandra	0.4	28	0.5	63
Jasminum sp.	+	14	+	51
Euonymus cochinchinensis	+	-	+	37
[illegible] sp.	+	[illegible]	+	[illegible]
Actephila collinsae	+	22	+	33
Tarenna longifolia	+	5	+	32
Atalantia scandens	+	28	+	31
Combretum procursum	+	12	1.4	30
Subtotal: composition	0.7		36.5	
Total % Composition	96.7		95.[illegible]	

a/ Trace
b/ None

Source: Darrow (1966).

"Most of the burning of the forest in Annam, or Central Vietnam, is done, as elsewhere, for shifting cultivation, the 'rai' system widely adopted throughout Southeast Asia. In this process thousands of acres of forests are burned each year, followed by the planting of crops mainly for food. After two or three harvests, the patches are abandoned. Soon a series of grasses, particularly the ubiquitous Imperata cylindrica, sedges, and such weeds as Eupatorium odoratum develop. Even in normal times this practice of slash and burn is difficult to suppress among the tribes in the mountain areas, although it can be controlled to some degree in the plains, where people are in closer contact with authorities. In some instances during a single year the inhabitants of a large village may destroy a considerable area of forest within a radius of 10 to 15 miles. Bamboo brakes are also destroyed by fire. The effect of this deforestation over a long period is evident also in Central and North Vietnam, as shown by a gradual increase of uncultivated land along the base of mountains, caused by erosion of soil from the bare upper slopes, filling up the stream beds and with consequent floods."

Response of Vegetation to Herbicides

The response of foliage to chemical treatment varies markedly--from little effect to plant kill.

Reports from observers in Vietnam likewise vary. Some say that defoliation is temporary or relatively ineffective; others state that the trees are dead and bare. The following verbatim reports, while somewhat conflicting, are probably accurate:

"The chemical mixture is supposed to kill all trees and brush, but the withering and dropping of leaves may take five days to three weeks." (Bigart, 1962)

". . . begin turning foliage brown in a matter of hours, but full results are not visible for six months." (Miller, 1967)

". . . Double or triple canopy jungle generally requires two applications, with the second application four to six weeks after the first. . .gives effective vegetation control for nine to 12 months." (Farm Chemicals, 1966c)

"Practically all the vegetation in the sprayed areas was dead and almost complete (estimated 95%) defoliation had resulted." (Armed Forces Chem. Journal, 1964c)

"Within several weeks they cause leaves on trees and other vegetation to wither away." (Washington Daily News, February 6, 1967)

". . . a powerful chemical killer which destroys all but the biggest trees. . ." (Lucas, 1967)

". . . within 24 hours the foliage begins to wither and turn brown; within five or six weeks, the leaves curl and fall." (Pruden, 1966)

"Within three days after a single spraying . . . the effects are noticeable. Within a week there is an 'autumn' effect. But three months must pass before the 'winter in Vermont' effect is achieved. Four months after that, however, the foliage begins to grow back." (Mohr, 1965)

Such diversity of reports is not surprising when consideration is given to:

* The remarkable number of woody plants found (1,500);
* The great diversity of plant communities found;
* Effects of seasonal changes; monsoons;
* Differences among herbicides used; and
* Application conditions which range from optimum to unfavorable.

Few if any scientific reports are available from the areas of operational use in Vietnam. The targets sprayed are frequently in enemy strongholds. The most useful data on response to herbicide treatment come from carefully conducted tests carried out in Thailand, Puerto Rico, and Texas (Tschirley, 1967c, and Darrow, 1966c). From these studies certain general observations have been drawn concerning the behavior of tropical vegetation and forest when aerially sprayed with military defoliants.

1. Degree of Defoliation: Maximum defoliation responses of 85 to 95% have been recorded, but complete defoliation of all species has not been obtained in any test plot of mixed forest.

2. Rate of Defoliation Response: The phenoxy herbicides and other systemic defoliants which are absorbed and translocated throughout woody plants produce abscission and leaf drop over a period of several months. Generalizations are difficult when dealing with so many factors, but perhaps two to three months are required as an average to reach maximum leaf removal.

Figure V-7 shows the defoliation response from "Orange" with maximum leaf drop between two and four months. At the end of seven months, the lianas have grown new leaves, and some of the foliage is returning to the trees.

Desiccants and contact herbicides produce leaf necrosis, loss of moisture and withering more rapidly; about two to three weeks on the average.

Similar photos, Figure V-8, show the desiccation achieved from cacodylic acid ("Blue"). In three weeks the leaves have curled, and most have fallen. Regrowth is under way three months after treatment. Table V-3 compares the percentage of defoliant obtained with various herbicides for a period of one year.

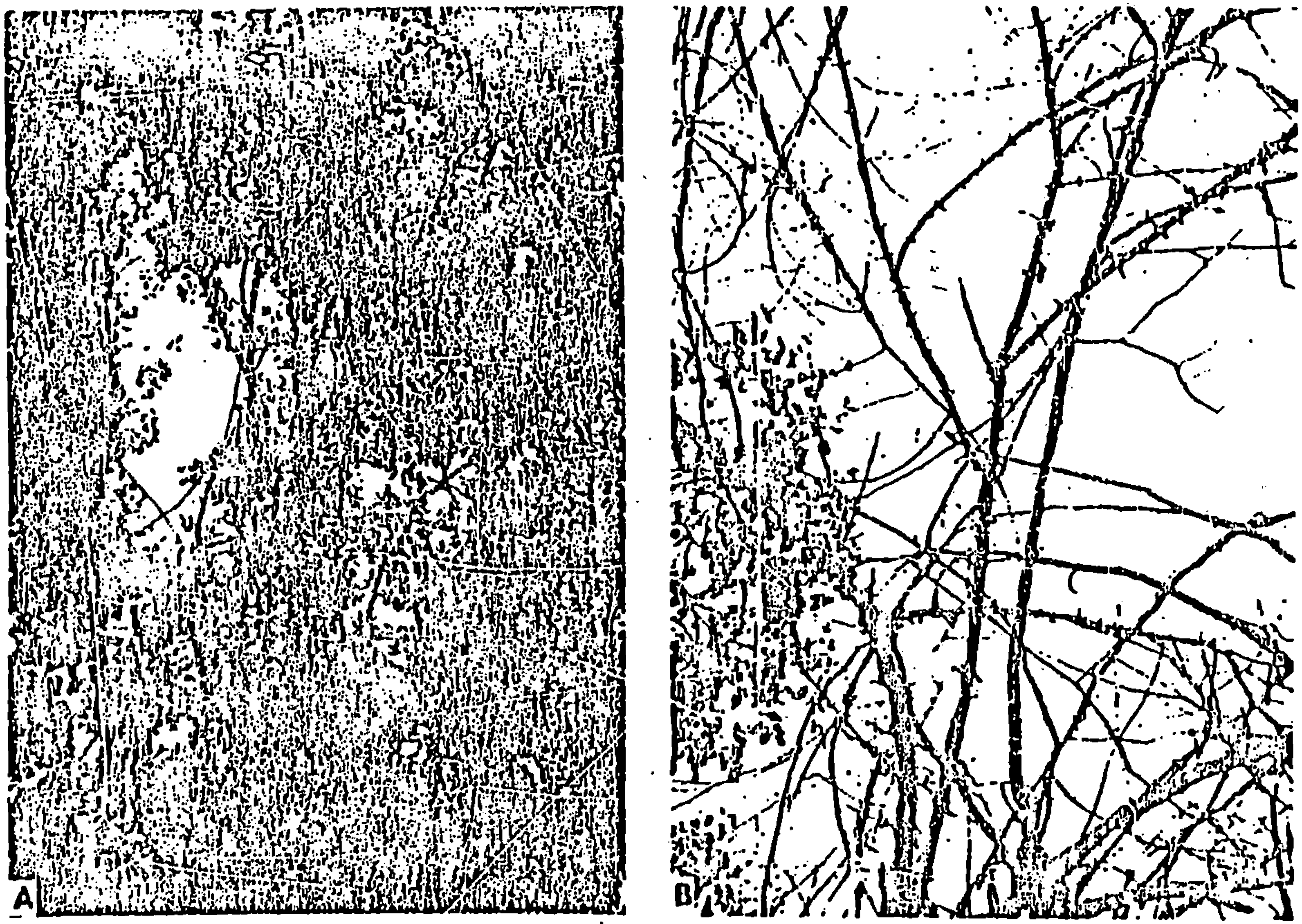
More detailed data are presented for various rates of application and other agents in the Appendix, Tables A-1 (p.297), A-2 (p.301) and A-3 (p.303).

3. Duration of Defoliation: Some trees and other woody plants are killed; others show topkill only. Many trees recover, growing new leaves within a year. Root sprouting occurs with some species. Certain species of trees, including Streblus zeylanica, Hydnocarpus ilicifolius, and several Diospyros spp. are relatively resistant to defoliation. Detailed analysis of species response is being compiled (Darrow, 1966d).

Figure V-9 shows the influence of application rate on the duration of effective defoliation, and length of time to 50% recovery.

It is problematical whether trees exhibiting complete defoliation like that of Figure V-10 will recover. The percentage of trees in mixed forest stands which show total kill after 12 months or longer has elapsed is not known.

4. Seasonal Effects: 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. The defoliation response to all systemic herbicides such as "Orange," "White" and "Purple" was more rapid and more complete during the rainy season, with its generally favorable soil moisture and growing conditions, than during the dry season. Lower rates of chemical treatments are necessary during periods of active growth.



Before Treatment, February 1965 — Two Months After Treatment

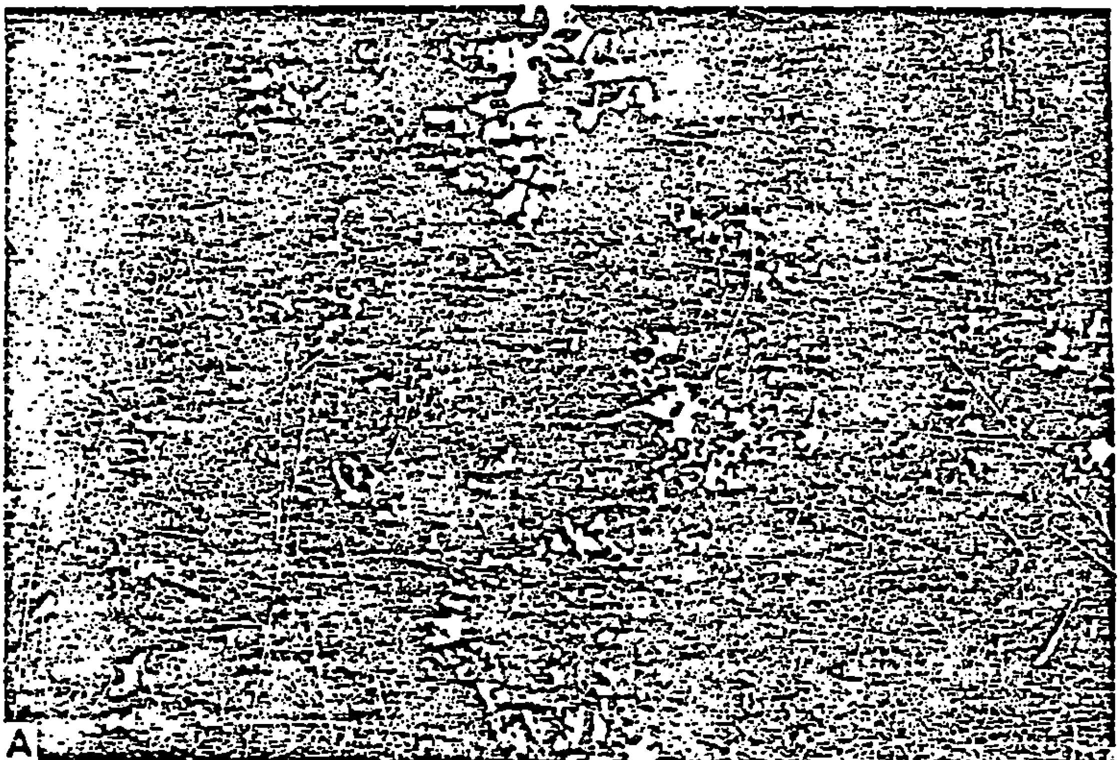
Figure V-7 - Defoliation Response from Orange Applied at 2.4 Gal/Acre (21 Lb/Acre AE)
(Courtesy U.S. Army Biological Laboratories, Ft. Detrick)

Four Months after Treatment

Figure V-7 (C

Seven Months after Treatment
(Note the regrowth of vines)

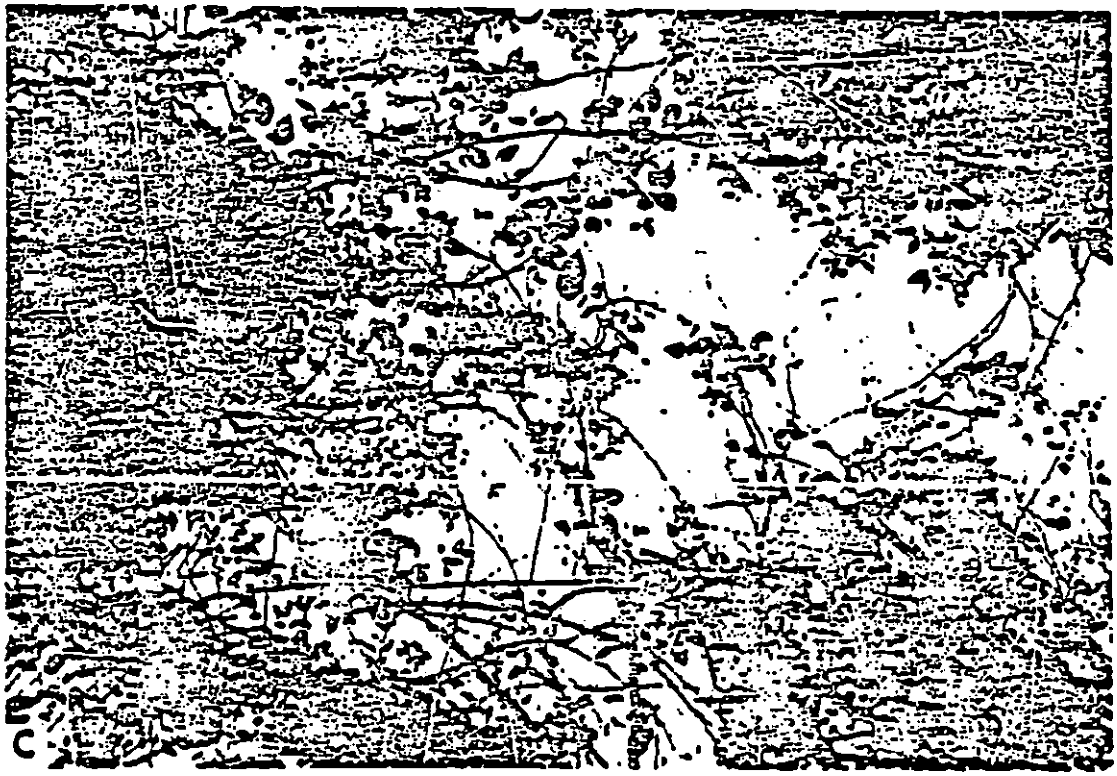
on luded)



Pretreatment, May 1964

Three Weeks after Treatment at Maximum Effect

Figure V-8 - Defoliation Response from Blue (cacodylic acid) Applied at 1.5 Gal/Acre (4.5 Lb/Acre AE) (Courtesy U.S. Army Biological Laboratories, Ft. Detrick)



Three Months - Showing Regrowth

Figure V-8 (Concluded)

TABLE V-3

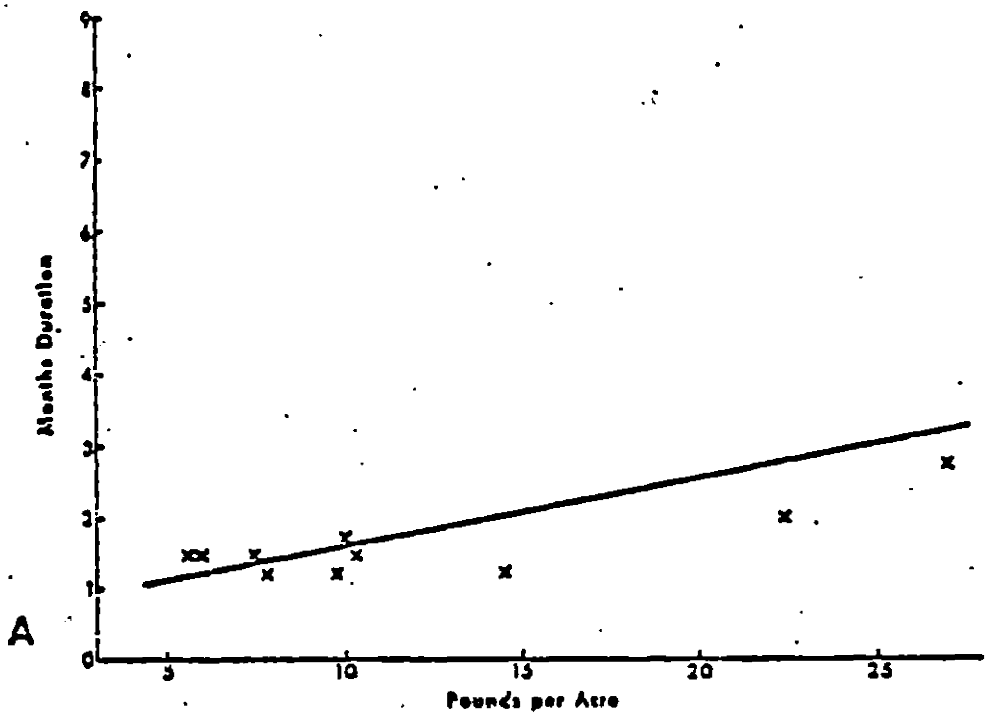
THE PERCENTAGE OF DESICCATION AND DEFOLIATION RESULTING FROM HERBICIDES APPLIED AS LOW-VOLUME AERIAL SPRAYS ON RAIN FOREST VEGETATION

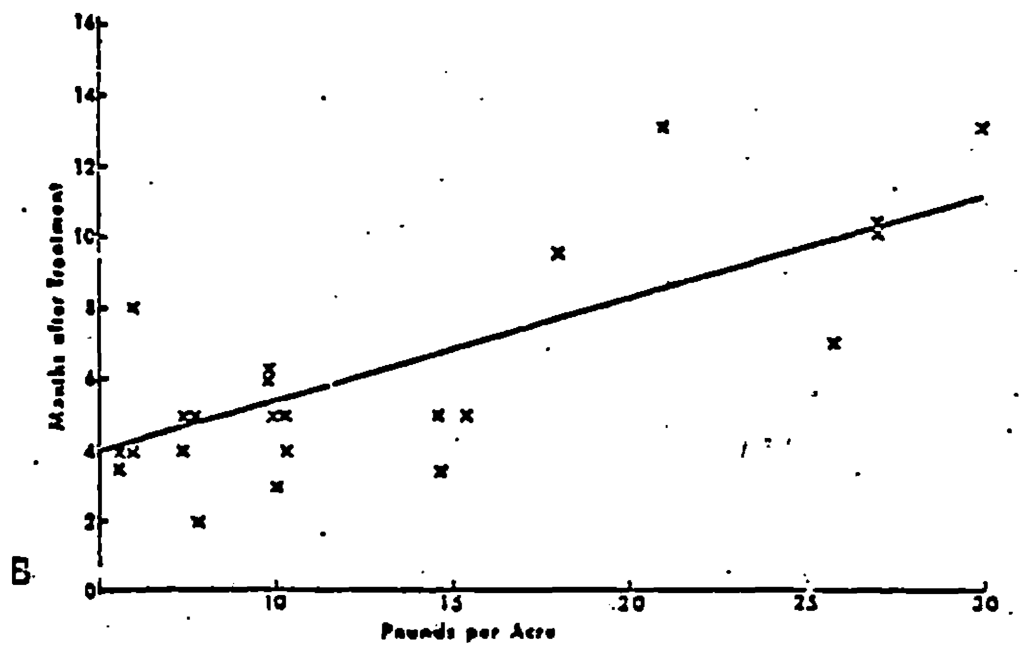
Herbicide[a]	Treatment Gal/Acre	Treatment Lb/Acre	Time After Treatment 1 Wk. (%)[b]	2 Wk. (%)	1 Mo. (%)	3 Mo. (%)	6 Mo. (%)	1 Yr. (%)
Orange	1.5	12	9/3	53/28	63/[illegible]	65	52	38
	→ 3.0	24	15/8	73/32	8[illegible]/73	79	66	54
	6.0	48	28/10	79/37	[illegible]/75	91	71	61
Picloram	1.5	3	8/0	24/14	34/32	29	27	30
	→ 3.0	6	8/0	51/21	70/52	30	50	54
	6.0	12	19/9	51/22	78/66	83	76	74
2,4,5-T Plus Picloram (4:1)	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	39/13	62/45	77	73	69
Paraquat	1.5	3	15/9	25/15	27/25	15	9	10
	→ 3.0	6	29/13	51/29	68/63	51	41	30
	→ 6.0	12	38/23	53/35	60/55	43	15	17

a/ Arrows denote typical rates.

b/ 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.

Source: (Tschirley, 1967).



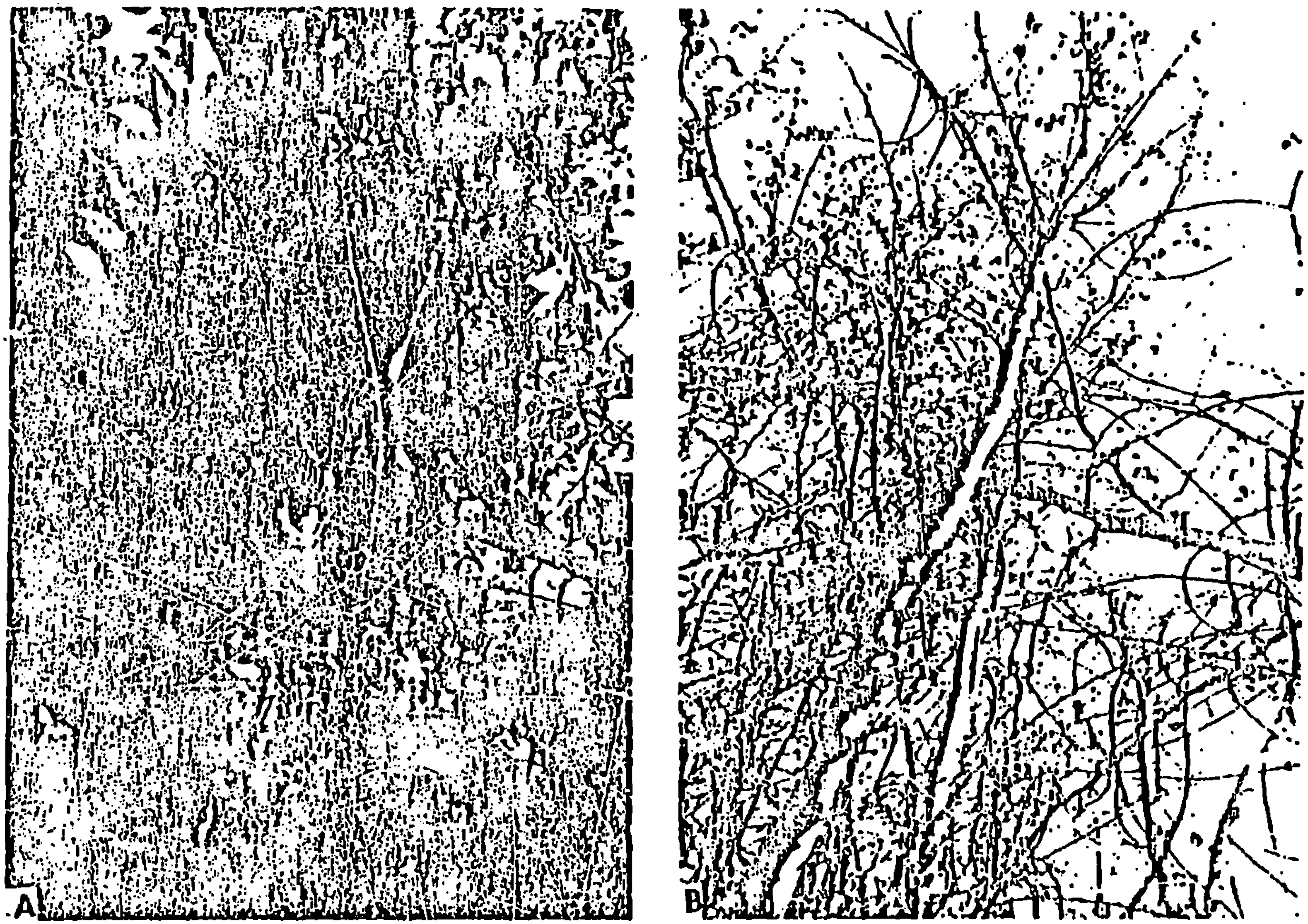


Source: Tschirley (1967)

Figure V-9 - Duration of Defoliation Response from Application of Purple as Related to Dosage Rate.

A. Duration of maximum percent decrease in obscuration. Data represent mean treatment values.

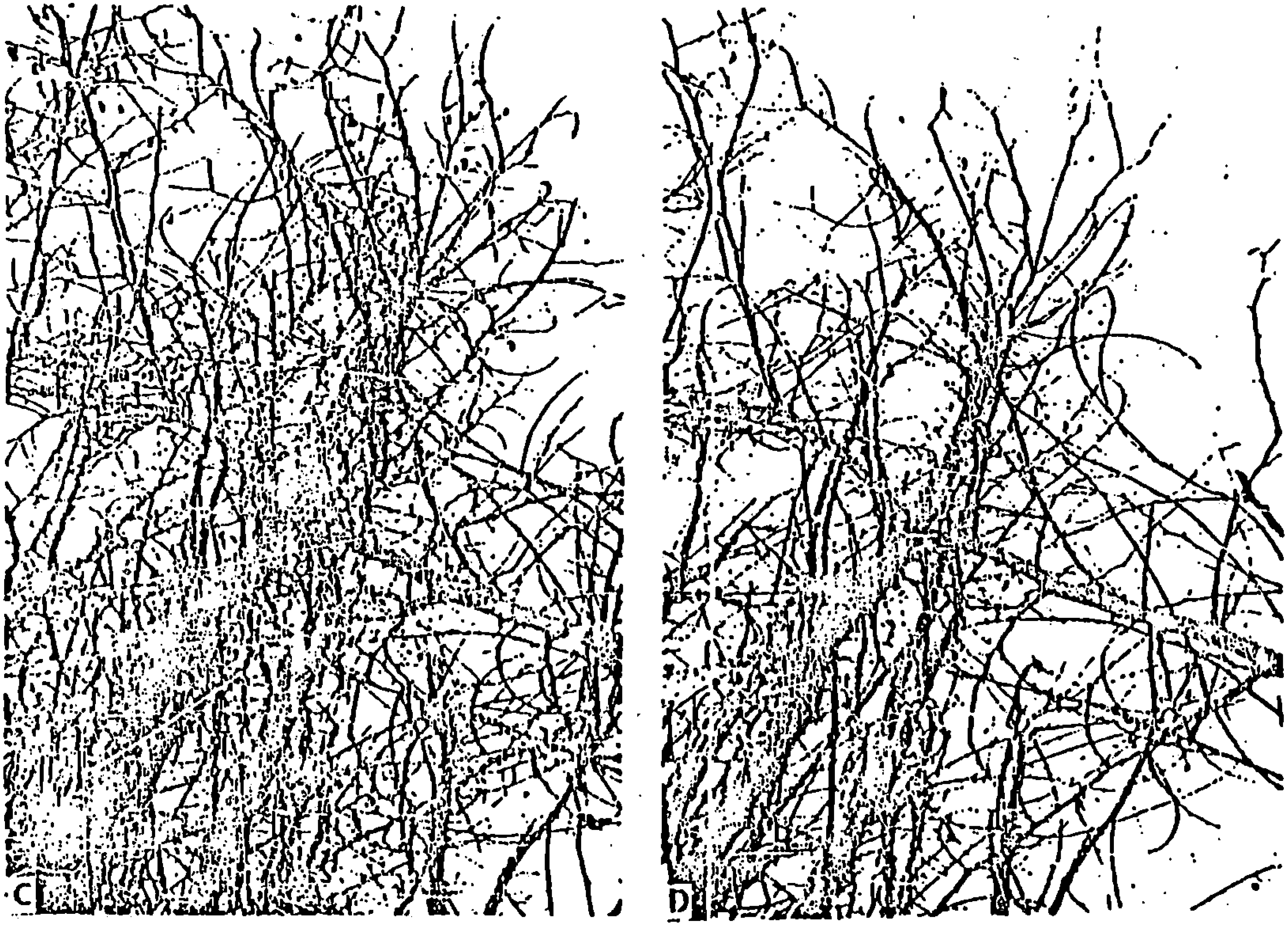
B. Number of months until 50% recovery from maximum response. Data represent individual plot values.



Before Treatment, December 1964

Three Months After Treatment

Figure V-10 - Defoliation Response from Purple Applied at 3.0 Gal/Acre (26.7 Lb/Acre AE)
(Courtesy U.S. Army Biological Laboratories, Ft. Detrick)



Six Months After Treatment

Nine Months After Treatment

Figure V-10 (Concluded)

In areas such as evergreen and broad-leaved Rain forest where rainfall is high but uniformly distributed throughout the year, woody plants are less subject to seasonal susceptibility.

Seasonal effects are reflected in the level of treatment needed for effective defoliation of mixed forest stands of different canopy density. These herbicide levels are summarized in Table V-4. More detailed conclusions regarding herbicide effects observed in tropical forest tests are presented in the Appendix, pp. 294-296, Figure A-1 (p.299), and Figure A-2 (p.300).

Revegetation and Succession

Tropical forest stands sprayed with quantities of systemic herbicides sufficient to kill or produce more than 85% defoliation show a general pattern of revegetation similar in some respects to that found in abandoned forest clearings. The seral successions observed in these devegetated areas have been described by Llewelyn Williams (Tschirley, 1967c).

The forests of Southeast Asia, and Puerto Rico have suffered severely over the centuries from human disturbance through falling of trees for construction timbers, fuelwood, and charcoal, or to clear land for agricultural use. Considerable changes in the vegetation have been caused by fires, either spontaneously or deliberately set, grazing by domesticated animals and wildlife, and damage by insect pests. 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 or 2% 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 tropical Rain forest is a prime example of a plant community in which rainfall, soil, and vegetation are the principal factors that contribute to the maintenance of a complex equilibrium. When one of the components of the primary forest is partly or completely destroyed, the other factors are altered and a new type of plant cover appears that is adapted to the modified environment.

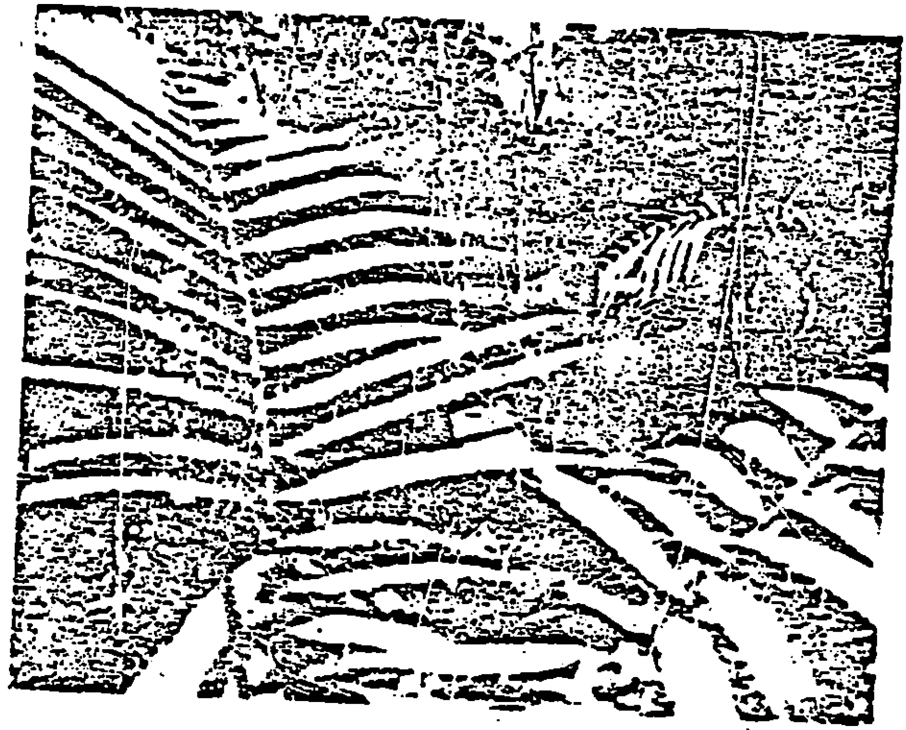
The general pattern of regrowth is essentially the same in tropical America as in Southeast Asia. Revegetation of disturbed areas follows a similar sequence in development of secondary growth, and the successional plant communities are similar in structure and phytosociology, but the species, of course, may be entirely distinct.

TABLE V-4

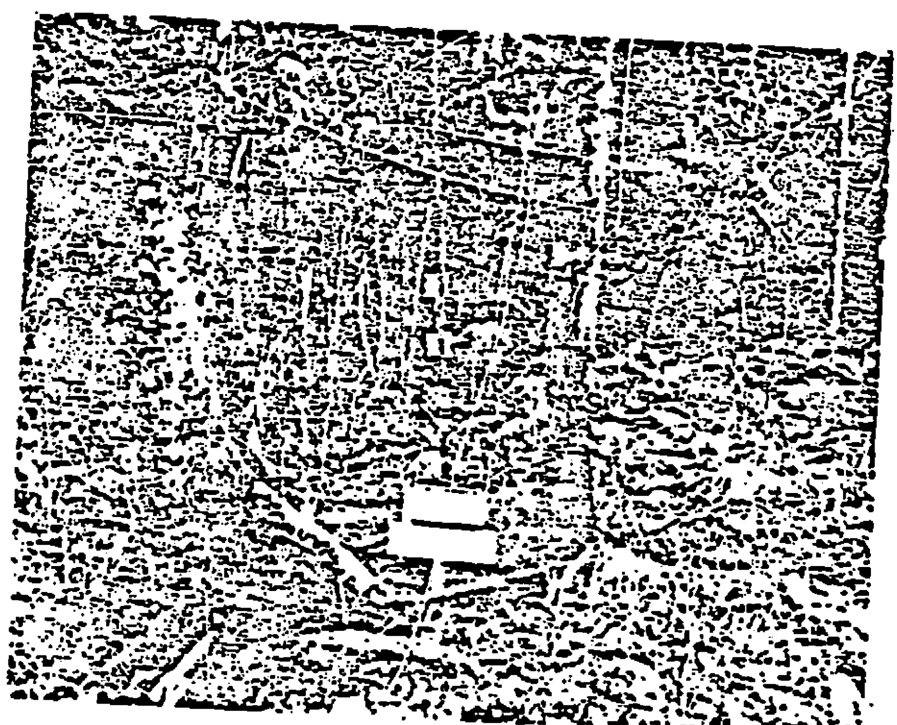
INFLUENCE OF SEASON AND FOLIAGE DENSITY ON HERBICIDE TREATMENTS REQUIRED FOR EFFECTIVE DEFOLIATION

Defoliation Requirement	Chemical	Rainy Season: Light to Moderate Cover (Single Canopy)	Rainy Season: Dense Cover (Multiple Canopy)	Dry Season: Light to Moderate Cover (Single Canopy)	Dry Season: Dense Cover (Multiple Canopy)
Fast, Short-Term Defoliation or Desiccation	Cacodylic Acid	5 to 6 lb/acre in 2.5 to 3.0 gal. spray Equal to Blue (65% cacodylic acid) at 7.7 to 9.2 lb/acre	5 to 6 lb/acre in 2.5 to 3.0 gal. spray Repeat application may be needed in 2 to 3 weeks for effective defoliation at ground level	5 to 6 lb/acre in 2.5 to 3.0 gal. spray Equal to Blue (65% cacodylic acid) at 7.7 to 9.2 lb/acre	5 to 6 lb/acre in 2.5 to 3.0 gal. spray Repeat application may be needed in 3 to 4 weeks for effective defoliation at ground level
Effective Defoliation (60 to 75%) for Moderate Duration, 3 to 4 Months	Purple or Orange	1.5 to 2.0 gal/acre undiluted or in 1:1 mixture with diesel fuel	2.0 to 2.5 gal/acre undiluted Repeat application may be needed after 2 months	2.5 to 3.0 gal/acre undiluted	2.5 to 3.0 gal/acre undiluted
Maximum Defoliation and Duration, 6 months or more	Purple or Orange	2.5 to 3.0 gal/acre undiluted	2.5 to 3.0 gal/acre undiluted Repeat application may be needed after 2 months	2.5 to 3.0 gal/acre undiluted	3.0 or more gal/acre undiluted Repeated application may be needed in following rainy season

Source: (Darrow, 1966d).



Forest Underbrush before Treatment, February [illegible]



Ten Months Following Treatment, December 1965

Figure V-11 - Herbicide Treatment Improves Horizontal Visibility Reducing the Opportunity for Ambush (Courtesy F. Tschirley)

The first stage of successional growth that develops following disturbance of dense, humid forest is usually dominated by grasses and weeds. These are generally short-lived, of less than one year. As a rule, in cleared areas such as these abandoned in shifting agriculture the plants that develop in the initial stage of secondary growth are entirely different from those that grow in the primary forest; likewise, seldom do any species in the secondary growth appear in the primary forest. Forest stands disturbed by the application of herbicides may show appreciable regrowth of seedlings representative of the original woody plants due to root sprouting, from seeds present in the soil, or seedlings that may have survived the treatment.

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.

In Thailand two weeds that develop most abundantly in abandoned land and in forest clearings are Eupatorium ordoratum, 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 bananas (Musa) appear. In many areas in Thailand, as in the other Mekong Basin countries, the weeds, 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 cutover stands of teak, as well as in the humid Evergreen forest.

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, among the most frequent trees in secondary forests are "Yagrumo hembra" (Cecropia) and "Yagrumo macho" (Didymopanax). Both propagate naturally and their growth is rapid.

Figure V-12 - Revegetation after One Year in Forest Opening Created by Heavy Application of Herbicide. Bamboo forest is the dominant successor, with various grasses and woody plants covering the ground layer. (Courtesy F. Tschirley)

Extent of Herbicide Application

There has been a steadily increasing pace in defoliation flights since the first operational employment of herbicides.

In the last two months of 1962, when spray flights first started, only 60 missions were flown. Only 107 missions were logged in all of 1962 (Pruden, 1966); however, by 1966 over 3,000 sorties were flown (Bloomington Daily Herald, 1966)

Chemical consumption shows that over 90% of the herbicides sprayed are systemics (Orange, White or Purple), while considerably less than 10% has been cacodylic acid for desiccation and destroying rice.

The following table shows the approximate extent and distribution of herbicide application from 1962 to date.

ESTIMATED* AREA HERBICIDALLY TREATED** IN SOUTH VIETNAM

Year	Acres Sprayed/Year		
	Defoliation	Crop Destruction	Total of Both
1962	17,119	717	17,836
1963	34,517	297	34,814
1964	53,873	10,136	64,009
1965	94,726	49,637	144,363
(Jan.-June 1966)			(195,537)
1966	775,894	112,678	888,572
(Jan.-Sept. 1967)	843,606	121,400	965,006

Sources: DOD data, contained in various releases.

* Not actual land area measurement. Areas were estimated from the number of sorties flown, calibrated spray rates and average width of spray swath covered.

** Treated area includes all respraying. Some areas are retreated annually (or more often if needed); no estimate is available on the extent of reapplication. The actual area is believed to be substantially lower than the figures here show.