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Morgan Bearden

DTIC

Information Manual
for Vegetation Control
in Southeast Asia

12/1969

Technical Report

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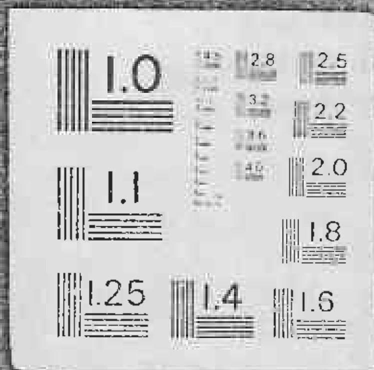

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MISCELLANEOUS PUBLICATION 33

INFORMATION MANUAL FOR VEGETATION CONTROL IN SOUTHEAST ASIA

Kent R. Irish
Robert A. Darrow
Charles E. Minarik

DECEMBER 1969

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MISCELLANEOUS PUBLICATION 33

INFORMATION MANUAL FOR VEGETATION CONTROL IN SOUTHEAST ASIA

Kent R. Irish

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Plant Physiology Division
PLANT SCIENCES LABORATORIES

Project 1B562602A061

December 1969

FOREWORD

This document is designed for the use of all echelons concerned with the research, development, employment, logistics, and/or planning of operations involving the use of the available chemical vegetation-control systems. While the data are related directly to Vietnam, most, if not all, are broadly applicable to other possible theaters of war and will serve to advise potential users of current capabilities.

The basic material in the document has been obtained from publications prepared by and for organizations in the Department of Defense. Published material was complemented by unpublished records of tests, observations of research and operations personnel, and informal correspondence, memoranda for record, and notes.

It is not anticipated that this document will be revised on a continuing basis; however, it is expected that as new data and materiel of special significance are developed and recommended for service use, addenda and/or supplements will be prepared and distributed. Constructive comments and recommendations for improving this document are invited and encouraged.

ABSTRACT

Information is provided on chemical vegetation-control systems employed in Vietnam for defoliation, destruction of screening vegetation, and denial of agricultural products (mainly food) to the enemy. Pertinent technical data on research, development, and tests of agents and dissemination systems currently in use are emphasized. The large volume of documentary material has been screened and summary information selected or prepared with a view toward the possible utilization of the data by personnel involved in support and employment of the weapon systems.

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I. INTRODUCTION*

A. HISTORY

The vegetation-control systems that have been employed so intensively and successfully in Vietnam since early 1962 came into being as a result of early and continued RDT&E accomplished in the Plant Sciences Laboratories, Fort Detrick, Frederick, Maryland (formerly Crops Division, Camp Detrick).

1. Agent Research

Early in 1943, the Chemical Warfare Service (CWS) activated Camp Detrick. Crops Division was established with the mission to conduct research and development on chemical and biological antiplant agents. The early work was sensitive and highly classified, and publication of research data was withheld until the end of World War II. In June 1946, an entire issue of the Botanical Gazette was devoted to 18 select papers covering work accomplished during 1944 to 1945 on chemical growth regulators.[1] The work by personnel of Crops Division was initiated on the basis of earlier experiments by various scientists who had investigated the biological activities of certain growth-regulating substances and of the suggestion by Dr. E.J. Kraus, University of Chicago, that they might be useful as herbicides. The pioneering tests that followed firmly established the fact that a number of synthetic growth-regulating substances are potent herbicides having great military and agricultural significance. Other laboratories and groups participated in the Army effort on a contract basis; the United States Department of Agriculture and the University of Chicago conducted tests and evaluations of candidate compounds; the University of Ohio synthesized a large number of the chemicals used in the tests. By mid-1945 almost 1,100 test substances had been synthesized and subjected to screening studies. From this array, 2,4-dichlorophenoxyacetic acid (2,4-D) and 2,4,5-trichlorophenoxyacetic acid (2,4,5-T) were shown to possess outstanding herbicidal properties.[1] In subsequent years a large body of fundamental and applied research data was developed on growth regulators in general as well as on 2,4-D and 2,4,5-T specifically.[2]

Release of information on this new class of herbicides to the public after World War II precipitated a great flurry of research in all parts of the world and caused complete revolutionization of weed control practices. During 1960 (prior to military demands in Southeast Asia), it was estimated that the United States produced upward of 50 million pounds of these chemicals (2,4-D and 2,4,5-T) for agricultural uses. Since 1961, military requirements have caused further expansion of United States production capability.

* This report should not be used as a literature citation in material to be published in the open literature.

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4. C-123/MC-1 (Hourglass)

During 1960 to 1961, the 75 MC-1 (Hourglass) spray units in storage at Ogden AFB, Ogden, Utah, were declared surplus by the USAF. Concurrent with this action, Tactical Air Command personnel from the Special Aerial Spray Flight, Langley AFB, Virginia, visited Crops Division to obtain information on large-capacity chemical spray devices for possible use with insecticides in a newly acquired C-123 aircraft. They were advised of the characteristics, location, and availability of the Hourglass units. Subsequently, they obtained two of the units and prepared a design, and a C-123/Hourglass (MC-1) spray system for the dissemination of insecticides was fabricated in the shops of Olmsted AFB, Pennsylvania.

B. VIETNAM

1. Feasibility Studies

In May 1961, Crops Division, Fort Detrick, received a request from the Advanced Research Projects Agency (ARPA), Office of the Secretary of Defense (OSD) for information on the technical feasibility of defoliating jungle vegetation in Vietnam. Research on defoliation had not been funded for several years and no testing had ever been accomplished on vegetation comparable to that in Vietnam. However the technical judgment was made that if adequate resources were provided, militarily significant vegetation control could be demonstrated. On 6 June 1961, ARPA directed Fort Detrick to conduct defoliation studies in Vietnam as a part of Project AGILE. Within a 15-day period, experimental herbicides and spray devices, other vital equipment and supplies, and movement orders to Vietnam were obtained. The n-butyl 2,4-D and 2,4,5-T chemicals could not be obtained on the open market and less active commercial substitutes were procured; a surplus insecticide spray unit for C-47 aircraft and an insecticide spray device for the H-34 helicopter (HIDAL) were obtained; TDY orders for two Crops Division scientists were approved. In little more than 60 days after receipt of the OSD/ARPA orders, defoliation tests were initiated in Vietnam (10 August 1961) despite the development of almost insurmountable barriers to their accomplishment.[9,10] The test program was responsive to the objectives of two Tasks (Task 2, Anticrop; Task 20, Defoliation) established as a part of the joint US/VN program of Military Assistance Advisory Group R&D Division and the Vietnamese Combat Development Test Center. During the period 10 August through 18 September, eight different spray tests were conducted with the various spray systems and chemicals available. One Task 2 trial served as an unqualifiedly successful demonstration and was not repeated; results from the Task 20 tests were varied. The test data and variations in effects were carefully evaluated by the test personnel and two salient facts were apparent: (i) the limitations imposed by the inadequate spray devices served to prohibit application of desired amounts of the dilute chemicals and (ii) vegetation responses in the test areas (regardless of doses delivered) demonstrated that, with suitable spray systems and the more potent chemicals of choice (n-butyl 2,4-D and 2,4,5-T), militarily significant defoliation could be accomplished in Vietnam.

2. Improved Employment Capabilities

Even though tight security restrictions were imposed on the early efforts, the activities attracted considerable attention among friendly and enemy forces. Without full information on the nature of the tests and equipment limitations, an undue amount of controversy and criticism developed within official US circles. Attitudes of uncertainty, doubt, and perhaps even hostility toward the concepts per se placed the program in jeopardy. At the height of the controversy, General Maxwell Taylor and Mr. Walt W. Rostow, advisors to President Kennedy, visited South Vietnam. The Crops Division Test Officer accompanied them on a 2-day aerial trip throughout RVN, during which time the defoliation program was discussed and the test sites were observed. The Presidential Advisors were impressed with what they saw and urged that the effort be continued. The visitors were provided with a written review and analysis of the test program to that date (October 1961) that also included a recommendation that the Special Air Spray Flight, Langley AFB, Virginia, be considered to assist if the decision were made to scale-up the spray operations in Vietnam.[11] Subsequently, six C-123 aircraft were made available to the Tactical Air Command with a high-priority directive to install spray equipment capable of disseminating vegetation-control agents. USAF and Fort Detrick personnel determined that the C-123/Hourglass configuration, developed by the spray unit at Langley AFB, should serve as a model for the new systems. Fabrication was accomplished expeditiously and on 6 December 1961 the six units and Tactical Air Command support personnel arrived at Clark AFB, Philippines. On 7 January 1962, three of the systems were moved to Tan Son Nhut, RVN, with the task of conducting further studies on the defoliation concept. This USAF effort was named RANCH HAND. The skill and dedication of this first RANCH HAND crew contributed immeasurably to the successes that followed and the development and ultimate acceptance by the Department of Defense of a new, non-conventional weapon system.

C. OPERATIONAL TESTING - 1962

1. C-123/MC-1/PURPLE Spray System

Three C-123 spray ships arrived in Vietnam on 7 January; the first shipment of PURPLE and BLUE was received on 9 January. The color codes were applied to the test chemicals primarily because security did not permit descriptive labels on the shipments. The colored bands painted around the drums also served as an aid to identification by support personnel. PURPLE code material was a mixture of *n*-butyl 2,4-D, *n*-butyl 2,4,5-T and isobutyl 2,4,5-T. The isobutyl portion (20%) was included as a measure to depress the freezing point of 2,4,5-T, which freezes at room temperature. (This mixture eventually was replaced by ORANGE.) BLUE consisted of a water-soluble powder that contained, as the active ingredient, 65% cacodylic acid (later replaced by a liquid formulation). On 10 January, the new C-123 spray system was tested as a functional check using PURPLE. The equipment previously had been tested with water but not with more viscous materials such as PURPLE. The objective of this test and later missions was to disseminate at a rate suitable to obtain a ground deposit of 1 gal/acre. It was estimated that the first test achieved a ground deposit of 0.8 gal/acre; in the second test on 13 January, 1.05 gal/acre deposit was achieved.[10] Concurrent with studies on the C-123 system, additional testing with the Vietnamese Air Force H-34/HIDAL system and ground equipment using BLUE was accomplished.

Evaluation of the upland forest areas treated with PURPLE showed that the vegetation did not respond as anticipated. By the end of January it was determined that the dry season had induced a dormant condition with respect to plant growth, and the biological response to the growth regulator chemical was being delayed. The USAF spray testing was continued through March 1962, at which time the effort was terminated to await a full evaluation of the results from the tests.

2. OSD/ARPA Evaluation

The evaluation was, in large part, stimulated by the appearance of several controversial news articles about the defoliation program. Because the test program was sensitive and classified, the news correspondents were only partially "informed" and the news accounts were something less than wholly factual. At the direction of OSD/ARPA, a selected team was assigned to evaluate thoroughly the vegetation-control program in Vietnam. The team of five with representatives from U.S.D.A., ARPA, and the Chemical Corps was headed by the Commanding General, USA Chemical Corps R&D Command. The team recognized two phases: Research Phase, 15 July 1961 to 12 January 1962; and Operational Phase, 13 January 1962 to 15 March 1962.[12,13] After an intensive evaluation of 21 treated targets in 11 areas the team concluded (in brief) that: (i) the operational program of vegetation control should be continued, with modifications recommended by the team; (ii) chemical applications, when evaluated from the air, were 70% effective in achieving stated objectives, and from the ground were 60% effective; (iii) limitation in dispersal equipment had a major influence on reduced mission effects, and modifications were required; (iv) PURPLE gave excellent control of mangrove; (v) additional information on defoliation should be developed in localities where the test personnel will have ready access to test areas; and (vi) the technical feasibility for control of all crop plants with available chemicals is well established.

The team developed a series of recommendations that included: (i) modification of the C-123 system to deliver 1.5 gal of PURPLE per acre and provide for a total application of 3 gal/acre; (ii) the spray spectrum should have a mass median diameter of 300 μ; and (iii) an expedited RDT&E program on defoliation should be initiated in USA and Thailand and should include investigations on a spray system capable of delivering 3 gal/acre of PURPLE.[12]

Subsequent actions taken to implement the recommendations of the evaluation team ushered in a period characterized by intensive RDT&E in Crops Division, Fort Detrick, and in Air Force Armament Test Laboratory (AFATL), Eglin AFB, to provide improvements of spray system components in support of RANCH HAND. Concurrently, operational employment of the spray capability by the RANCH HAND units was intensified steadily with time and availability of resources.

II. VEGETATION-CONTROL CONCEPTS

A. DEFOLIATION

In the military sense, defoliation is the destruction and/or removal of target foliage by the application of chemical agents. The objective of defoliation is to improve vertical and horizontal visibility within the treated area. The high incidence of successful enemy ambushes in Vietnam was the salient factor that influenced the introduction of vegetation-control systems into the Southeast Asia conflict. The initial objective of Task 20 was to defoliate the vegetation along lines of communication (highways and waterways) to deny the enemy the safety of adequate cover and concealment (Fig. 1).

Three general classes of defoliant agents are recognized according to their modes of action:

1) Growth regulators. Chemicals in this class are hormone-like substances that have some characteristics similar to those of natural plant hormones, are readily absorbed by the treated foliage, and enter into the plant system to be translocated and affect other parts of the plant. Because they are alien, they disrupt the normal physiologic processes of the entire plant system (systemic effects). Sensitive perennial species shed their leaves and, if the dose of chemical is adequate, die.[3] Plants treated with sublethal doses frequently recover partially or completely; also, some plant species are highly resistant to this class of chemicals and, outwardly, may appear unaffected.[14] Growth regulators as a class are most effective on broad-leaved plants in an active state of growth. Because these agents function systemically, small quantities may be highly effective, but while absorption into the plant system is rapid, development of effects is relatively slow. Agents ORANGE and WHITE are classic examples of systemic growth regulators.

2) Desiccants. Chemical agents in this class are also referred to as contact agents because they produce their effects locally at the point of application. These chemicals cause rapid desiccation (drying) of the treated foliage. This action leads to leaf fall with some species while on others the leaves shrivel and die but remain on the plant. The desiccant chemicals normally do not kill perennial woody and herbaceous plants and, in the tropics, refoliation occurs in 30 to 90 days, depending on the species. Agent BLUE is a desiccant that is effective on grassy plants resistant to the growth regulators and on broad-leaved plants in a dormant stage of growth, such as those in upland forests during the dry season in Vietnam. Because these chemicals are not normally translocated to produce their toxic effects, thorough coverage of the target foliage is required.

FIGURE 1. Defoliation in Mangrove Vegetation Along Waterway in RVN.

3) Defoliant (true). One of the outstanding goals of research on vegetation-control agents is development of a militarily useful, true defoliating agent. An intensive research effort is devoted to the physical and biochemical processes involved in the normal leaf senescence and abscission phenomena. The objective is to discover the chemical basis for the processes and to develop means of inducing leaf fall at will as it normally occurs in temperate zones with the onset of fall and winter. A compound capable of this type of action also is being sought in the screening program in progress at the Plant Sciences Laboratories, Fort Detrick.

B. CONTROL OF CROP PLANTS

The vegetation-control agents currently in use in Vietnam are capable collectively of damaging or destroying the productivity of all known agricultural crop plants of significance.

1. Agent ORANGE

Each of the two components of ORANGE (2,4-D and 2,4,5-T) is effective against a wide array of broad-leaved plant species. Certain of the plants are sensitive to both chemicals, while others are affected by only one; thus the 50:50 mixture, ORANGE, provides the military with a capability to attack an extensive array of broad-leaved crop plants.[3] Unfortunately, ORANGE is considered to be generally ineffective on grasses. Important cereal crop plants such as rice, wheat, corn, sugarcane, sorghum, millet, and barley are grasses and a second chemical is required for their control. In the search for a universal anticrop agent the herbicidal properties of cacodylic acid (dimethylarsinic acid) were discovered. Studies on this new compound showed it to be highly effective against rice in particular and other grasses in general as well as a number of broad-leaved crops.[15,16]

2. Agent BLUE

Cacodylic acid (agent BLUE) as a dry, water-soluble powder was introduced into Vietnam as the agent of choice for destruction of Viet Cong rice crops. Mixing with water was required. Later, a commercial, liquid formulation of sodium cacodylate, Phytar 560G, was introduced as a replacement for cacodylic acid and is the agent BLUE currently in use.

3. Agent WHITE

Tordon 101, a proprietary formulation of picloram (4-amino-3,5,6-trichloropicolinic acid) and 2,4-D, was introduced into Vietnam by Department of the Army, Assistant Chief of Staff for Force Development, for use as a substitute for ORANGE on targets in the proximity of sensitive crop plants, principally rubber. Allegedly, the vapors from

ORANGE had occasionally caused crop losses in the vicinity of defoliation strikes, and a less volatile chemical was requested by US Military Assistance Command, Vietnam, for use on a number of targets. Picloram, the proprietary, active ingredient in Tordon 101 and a variety of newer formulations, is a highly potent, systemic herbicide for a wide variety of broad-leaved crop plants. On the basis of claims by the manufacturer (Dow) and the results of testing by Fort Detrick, it is indicated that picloram will control essentially the same broad array of crop species as ORANGE but on some will be effective at significantly lower dosages. Picloram is even less effective on grasses, in general, than ORANGE, with but one notable exception — it is highly effective in reducing wheat yields. Unlike ORANGE, this compound is not readily inactivated by soil organisms and, because of its persistence, some restraints should be imposed on its use for control of crop plants.

4. Predictability

Crops can be successfully controlled by chemicals with a high degree of certainty because the required technology is well developed and target crop vulnerabilities are known. The number of important crop plants is limited and most have been subjected to tests by Fort Detrick, the U.S.D.A., various chemical companies, private research organizations, and/or universities. With but a few exceptions, crop plants are annuals, relatively small in size, normally in an active stage of growth, and sensitive to select compounds. Dose requirements for control of broad-leaved crops are very low. As little as 0.10 lb./acre of ORANGE is adequate to control such crops as soybeans, sweet potatoes, and garden beans, while manioc is damaged by 1.0 lb./acre. Rice is destroyed by 0.5 to 1.0 lb./acre of BLUE. Manioc may also be controlled effectively by the application of 0.2 lb. of picloram in Tordon 101.* Picloram at the rate of 0.04 to 0.07 lb./acre has caused up to 100% yield reduction of garden beans, potatoes, soybeans, peanuts, and sweet potatoes.

C. TARGET MARKING

The use of vegetation-control agents for marking targets has been considered for many years but research on this role has been limited. To satisfy this concept for employment in a tactical situation, a very fast-acting compound is required to produce a highly visible, contrasting change in the treated vegetation. A target-marking capability would probably find its greatest use in pinpointing targets for aerial strikes by high-performance, close-support aircraft and/or bombers.

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* Dr. R.C. Bunker, Plant Physiology Division, personal communication.

D. SPECIAL APPLICATIONS

The guerrilla-type war in Vietnam has created a new appreciation for advantages of stealth and surprise and the effective use by an aggressive enemy to exploit it to harass numerically superior forces. The US and RVN units have prepared elaborate defenses around base installations to guard against infiltration by the enemy and to prevent surprise attacks. Vegetation-control agents are used extensively to maintain vegetation-free fire lanes, minefields, fields of observation on perimeters, and defensive barrier areas. The cleared areas deny the enemy the cover and concealment vital for successfully launching surprise attacks and withdrawing with acceptable losses. All three agents have been used for maintenance of the defense areas, since control of both broad-leaved and grassy types is required. Recommendations have been made for the use of soil-applied chemical compounds for nonselective, long-term control, however use of such chemicals has not been approved.

III. VEGETATION-CONTROL AGENTS

A. ORANGE AND ORANGE II

ORANGE is the code designation for a 50:50 mixture of n-butyl esters of 2,4-dichlorophenoxyacetic acid (2,4-D) and 2,4,5-trichlorophenoxyacetic acid (2,4,5-T). The agent consists of a mixture of equal volumes of the undiluted technical esters of 2,4-D and 2,4,5-T. Approximate cost is $6.75/gal.

ORANGE II is a mixture of equal parts by volume of the n-butyl ester of 2,4-D and isooctyl ester of 2,4,5-T.

Specifications for ORANGE and ORANGE II are available in MIL-D-51239A (MU). Specifications for the component n-butyl esters of 2,4-D and 2,4,5-T and of isooctyl ester of 2,4,5-T in ORANGE II are as follows:

MIL H-51147, Herbicide; n-butyl 2,4-dichlorophenoxyacetate
MIL H-51148, Herbicide; n-butyl 2,4,5-trichlorophenoxyacetate
MIL H-60724, Herbicide; isooctyl 2,4,5-trichlorophenoxyacetate

1. Physical, Chemical, and Biological Properties

a. Physical State

ORANGE and ORANGE II are liquids at room temperature and above, varying from clear reddish brown to straw color. Both agents become more viscous at lower temperatures and may solidify at 40 to 45 F. n-Butyl ester of 2,4,5-T freezes below 70 to 75 F, but both n-butyl ester of 2,4-D and isooctyl ester of 2,4,5-T have considerably lower freezing points.

b. Solubility

ORANGE and ORANGE II are readily soluble in diesel fuel and other organic solvents, but are relatively insoluble in water.

c. Volatility

ORANGE and its component n-butyl esters of 2,4-D and 2,4,5-T are characterized by plant physiologists as volatile herbicides because the vapors are relatively phytotoxic. However, the physical chemist would regard the butyl esters of 2,4-D and 2,4,5-T as essentially nonvolatile, with a vapor pressure of less than 1 mm of mercury at 35 C. In fact, the n-butyl ester of 2,4-D is approximately equivalent to No. 2 diesel fuel in volatility, requiring a temperature of 147 C for vapor pressure to equal 1 mm of mercury.

ORANGE II, consisting in part of the low-volatile isooctyl ester of 2,4,5-T, may be considered less volatile than ORANGE.

Data are not available on the distances that ORANGE or its component esters may travel in vapor state from defoliated or sprayed areas, but lateral movements of herbicides, due to their volatile ature alone, are believed to be negligible. Most instances of alleged crop damage adjacent to areas sprayed with ORANGE may be attributed to drift or misapplication at the time of spraying rather than to volatility.

d. Corrosive Action

ORANGE and ORANGE II are noncorrosive on most metals but are deleterious to some paints, rubber, and neoprene. Teflon, polyethylene, Viton, and other similar plastic materials are generally resistant to deterioration by ORANGE.

e. Other Specific Properties

	ORANGE	ORANGE II
Freezing point, C	7 to 8	9
Viscosity, centipoises		
at 75 F	43	67
at 100 F	24	27
Weight, lb./gal		
Total esters	10.7	10.2
Acid equivalent	8.6	7.6
Specific gravity	1.275 to 1.295	1.220 to 1.242

f. Biological Properties

Consisting of two systemic or translocated herbicides (2,4-D, effective on broad-leaved herbaceous plants, and 2,4,5-T, effective on a broad array of woody plants), the mixture ORANGE is effective on a wide range of plant species, principally of the broad-leaved or dicotyledonous groups. Grasses and other monocotyledonous plants are less affected by ORANGE. The chemical is absorbed principally by the foliage but may enter the plant through the stems and/or root system. Decomposition of the two components, 2,4-D and 2,4,5-T, by soil microorganisms occurs rapidly and the chemical disappears from soils within 1 to 2 months following application.

2. Toxicology

Agent ORANGE is low in toxicity to man, fish, and wildlife, as shown in the long and extensive record of use of 2,4-D and 2,4,5-T for agricultural and industrial vegetation control.

ORANGE has a low oral mammalian toxicity. The LD_{50} for acute oral toxicity of ORANGE for rats is 550 mg/kg.* LD_{50} values for the 2,4-D

* B.P. McNamara, Toxicology Department, Edgewood Arsenal, Md. Summary of toxicity data on phenoxyacetates.

component of ORANGE range from 300 to 1,000 mg/kg for rats, guinea pigs, and rabbits. Toxicity to cattle appears to be similar to that of laboratory animals.

ORANGE and ORANGE II may cause slight skin irritation and minimal inhalation effects.

Toxicity of 2,4-D and 2,4,5-T to fish varies widely with the species, salt or ester employed, and duration of exposure.[17] Pure 2,4-D acid at 100 ppm concentration* caused only slight mortality to fingerling bream and largemouth bass.[18] Minnows and catfish tolerated sodium salt of 2,4-D at 2,000 ppm for 1 week but fingerling bluegills had losses of 40 to 100% from the butyl ester of 2,4-D at concentrations of 1 to 5 ppm. Ester forms of 2,4-D and 2,4,5-T are more toxic to fish than pure acid or salts which are used for control of aquatic vegetation without injury to fish.[19] Only under conditions of direct application of ORANGE to shallow bodies of water at the rate of 3 gal/acre would kill of the most sensitive species of fish be likely to occur.

3. Handling

Agents ORANGE and ORANGE II may be safely handled with ordinary sanitary precautions. Spillage on skin or clothing should be removed promptly to avoid possible irritation through prolonged skin contact. These chemicals present no hazard to man or animals in areas subjected to defoliation at the time of or following spray application.

ORANGE has a penetrating odor that tends to persist in enclosed areas such as aircraft cabins and storage areas. Spillage or spray deposit on aircraft and painted surfaces should be removed as soon as possible by washing with diesel fuel or other light petroleum oils, followed by a soap wash and thorough rinsing with clear water.

As indicated, exposure of rubber or neoprene hose to ORANGE causes deterioration. Transfer hoses, pump seals, and other equipment parts subjected to continued contact with this chemical should be checked often for replacement unless resistant materials such as Teflon and Viton are used.

Following herbicide application, the tank and spray system should be flushed with diesel fuel followed by a detergent or soap and water rinse and clear water rinse when change is made from ORANGE to a water-base agent such as BLUE or WHITE. This flushing and rinsing procedure is more important to follow when BLUE is used after ORANGE. WHITE may be

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* One ppm is the equivalent of 2.72 lb. of herbicide per acre-foot of water. If 3 gal of ORANGE were sprayed on an acre of water 1 foot deep, the concentration of 2,4-D + 2,4,5-T acid equivalent would be approximately 11 ppm.

used directly after ORANGE without flushing, as the small amount of residual ORANGE in the spray tank will mix with the larger quantity of WHITE without forming a precipitate. In the reverse situation when ORANGE is used after WHITE, the residual WHITE will tend to separate and float on top of the denser ORANGE unless the mixture is thoroughly agitated. In the A/A45Y-1 spray system used in the UC-123 aircraft, the circulating system is effective in keeping the residual agent (50 gal) mixed with the new fill (900 gal).

4. Methods of Disposal

Loading and storage areas subject to contamination by ORANGE by repeated spillage may be treated by repeated flushing of affected areas with diesel fuel and drainage into settling basins or pits for incorporation into soil where microbial and/or photodecomposition will occur. If possible, heavily contaminated soils should be deep-plowed to work the chemical into the soil to aid in subsequent leaching and decomposition.

Used containers and surplus quantities of ORANGE should be buried in deep pits at locations where minimal hazard exists for leaching into water supplies or cultivated crop areas.

Regular removal of used containers from loading areas should be practiced to avoid possible damage or hazard to nearby sensitive crops by concentrated vapors of the chemical or improper use of the empty containers in agricultural areas.

5. Effectiveness as a Defoliant

ORANGE and ORANGE II are effective defoliants of forest vegetation under temperate and tropical conditions. As systemic herbicides, the component esters of 2,4-D and 2,4,5-T cause death of the plant with accompanying defoliation.

The typical response of woody vegetation to a foliar application of ORANGE is first a browning and discoloration of the foliage within a period of 1 or 2 weeks. Foliage of the more susceptible species may turn brown rapidly and leaf drop will occur over a period of 1 to 2 months. Under tropical conditions, maximum defoliation may occur at 2 to 3 months after spray application (see Section IV,B,3). As herbicidal response continues, the stems and branches die back progressively from the tip, accompanied by defoliation. When only partial kill of the individual plant occurs, regrowth and new foliage develop from the main stems and larger branches.

Information on the degree and duration of defoliation responses from ORANGE is given in Section IV,B,3.

Under tropical forest conditions, satisfactory levels of defoliation may persist for 4 to 6 months or more after which regrowth and replacement vegetation may necessitate retreatment.

1. Physical, Chemical, and Biological Properties

a. Physical State

Cacodylic acid (technical) is a colorless, crystalline solid with a melting point of 200 C.

BLUE (Phytar 560G) is a liquid formulation of cacodylic acid and its sodium salt. It is a reddish or brownish, free-flowing liquid.

b. Solubility

Both cacodylic acid and the liquid formulation BLUE are readily soluble in water and alcohol but insoluble in diesel fuel and oils.

c. Volatility

BLUE is nonvolatile. Cacodylic acid and its salt have extremely low vapor pressures.

d. Corrosive Action

Corrosion tests with undiluted BLUE showed little or no effect on brass, copper, aluminum, and tin after an exposure of 1 month. Steel showed a rapid initial reaction and moderate corrosion with BLUE. Zinc was the least resistant metal, exhibiting a galvanic reaction in the cacodylate solution.

e. Other Specific Properties

Freezing point, F	Below -22
Viscosity, centipoises	
At 50 F	19.9
At 75 F	11.0
At 95 F	9.0
Weight, lb./gal	
Liquid formulation	10.9
Cacodylic acid equivalent	3.1
Specific gravity	1.31
pH	6.7 to 7.3

f. Biological Properties

BLUE is a desiccant or contact herbicide and causes rapid browning of foliage. It shows relatively little translocation or movement within the plant. Foliage of broad-leaved vegetation affected by BLUE may abscise or shrivel and remain on the plant. Grasses may show rapid browning and death of top growth but regrowth of resistant perennial species, such as elephant grass, may occur within 1 to 2 months. Defoliation of woody vegetation by BLUE shows short-term effect, with maximum effect at 2 to 6 weeks after treatment. Repeat applications of BLUE may be required for continued vegetation control of perennial grasses.

2. Toxicology

Cacodylic acid or dimethylarsinic acid, the active component of BLUE, contains arsenic in the innocuous pentavalent state rather than the toxic trivalent form. The acute oral toxicity (LD_{50}) of cacodylic acid in rats is 1,400 mg/kg for males and 1,280 mg/kg for females. For the formulation Phytar 560G or BLUE containing the acid and its sodium salt, the acute oral toxicity (LD_{50}) for rats is 2,600 mg/kg, a toxicity level lower than that of aspirin (1,750 mg/kg).*

Cattle fed 24.5 mg/kg of cacodylic acid daily in a 60-day feeding test showed no arsenic in the milk and no storage of arsenic in the animal body on a cumulative basis.

In tests with fish, Gambusia. shiner, and largemouth black bass were able to withstand concentrations of cacodylic acid of at least 100 ppm for 72 hours, a rate equivalent to 270 lb. of a chemical per acre-foot of water. It may, thus, be considered nontoxic to fish and animals.[17]

When BLUE or cacodylic acid is applied directly to soil, the chemical is rapidly adsorbed and deactivated by the soil colloids so that new crops can be planted during the same growing season.

3. Handling

BLUE may be handled safely with ordinary sanitary precautions in avoiding prolonged contact with skin or clothing. Cacodylic acid is readily absorbed through the skin; prolonged absorption may lead to a distinct garlic odor in the breath. Spillage should be avoided and removed by liberal flushing and rinsing with clear water.

Some difficulty has been encountered with precipitate in the commercial formulation. Drums should be checked to ensure that precipitate, if present, is not pumped into a spray system.

BLUE should not be used in a spray system either following or preceding WHITE without thoroughly flushing the tank and system with water. A mixture of these two agents results in a precipitate consisting of the sodium salt of 2,4-D (a component of WHITE). If a change in agents is to be made, the tanks or spray system should be filled at least half full with clear water and the system exhausted of liquid before the new agent (BLUE or WHITE) is added.

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* Unpublished data of the Ansul Co., Marinette, Wisconsin.

4. Methods of Disposal

Equipment used for application of BLUE should be thoroughly cleaned prior to storage or disuse. Several flushings of soapy or detergent water to which ammonia has been added may be used, followed by a clear rinse. For most spray systems a final rinse with diesel fuel may serve to prevent rust or sediment accumulation.

Excess spillage of BLUE in loading or storage areas should be removed by thorough washing with clear water and/or dilute ammonia. Runoff or wash water containing diluted BLUE should, if possible, be diverted into pits or settling basins for incorporation into soil. The chemical is rapidly adsorbed by soil and deactivated.

Used containers and residual chemical should be disposed of by burial whenever possible.

5. Effectiveness as a Defoliant

BLUE is primarily a desiccant with little or no systemic herbicidal action. When applied to broad-leaved, woody, or grass vegetation, BLUE causes a rapid browning and desiccation, with accompanying shriveling and abscission of leaves on some woody species. The agent may be considered a short-term defoliant on woody vegetation with maximum defoliation 2 to 4 weeks after application (see Section IV,B,3).

6. Effectiveness as an Anticrop Agent

BLUE is the agent of choice for destruction of cereal or grain crops (in contrast to ORANGE which is primarily effective on broad-leaved crops).

Early work at Fort Detrick with rice showed that yield reductions of 70 to 97% were obtained by a single application at 0.25 lb. cacodylic acid per acre at any time over a 2.5-month growth period.[2] Recent tests on rice with sodium cacodylate formulation (Phytar 560G) have shown complete yield reduction with applications of 1 lb./acre cacodylic acid on plants in the vegetative and flowering stages of growth.

Corn and grain sorghum are controlled effectively with BLUE in early growth stages (12 to 18 inches high) with 1 lb. cacodylic acid per acre; wheat and oats have shown complete yield reductions with 1 lb. cacodylic acid per acre applied as BLUE in the late boot stage. First year or plant crop of sugarcane in late season required 5 to 10 lb. cacodylic acid per acre for effective yield reduction; in ratoon crops more than 24 lb./acre are required.* The chemical is not recommended for this crop because better agents are available.

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* Dr. R.C. Bunker and Dr. W.C. LeCroy, Plant Physiology Division, personal communication.

C. WHITE

WHITE is the code designation for Tordon 101, a liquid formulation containing picloram (4-amino-3,5,6-trichloropicolinic acid) and 2,4-D in the form of triisopropanolamine salts. Approximate cost is $6.40/gal.

The composition of WHITE, based on weight of salt, is: picloram, 10.2%; 2,4-D, 39.6%. Based on weight of active ingredient or acid, the composition is: picloram, 5.7% or 0.54 lb./gal; 2,4-D, 21.2% or 2.0 lb./gal. The remainder consists of water, wetting agent, and other inert ingredients.

Picloram or Tordon is a proprietary item produced by Dow Chemical Company and is available in other formulations, including: (i) Tordon 40, a liquid containg 4 lb. isooctyl ester per gallon, soluble in oil, insoluble in water; (ii) Tordon 10K, an extruded pellet containing 10% picloram as potassium salt; and (iii) modified ORANGE (Dow M-3393).

An experimental formulation that has been proposed for testing contains a mixture of picloram ester, n-butyl ester of 2,4-D, and n-butyl ester of 2,4,5-T.

1. Physical, Chemical, and Biological Properties

a. Physical State

WHITE (Tordon 101) is a dark brown, somewhat viscous liquid.

b. Solubility

WHITE is miscible in water but insoluble in diesel fuel and other oils. The triisopropanolamine forms of 2,4-D and picloram in WHITE are both readily soluble in water, whereas the parent acids (2,4-D and picloram) are white crystalline powders, soluble in acetone and alcohol, and somewhat soluble in certain other organic solvents.

c. Volatility

WHITE is considered nonvolatile. Picloram has a vapor pressure of 6.16×10^{-7} mm of Hg at 35 C.

WHITE, because of the low volatility of its active ingredients, has been suggested as a substitute for ORANGE for defoliation in areas adjacent to rubber plantations and sensitive broad-leaved crops. However, because of the high activity of the picloram component, extremely small amounts can damage sensitive species.

WHITE is stable and moderately resistant to ultraviolet radiation. Despite its water base, the formulation WHITE is flammable with a flash point of 35 C.

d. Corrosive Action

WHITE is noncorrosive on common metals and materials used in spray equipment.

e. Other Specific Properties

Viscosity, centipoises	
At 10 C	362
At 25 C	125 to 135
At 38 C	95
Weight of active ingredients (acid equivalent), lb./gal	
Picloram	0.54
2,4-D	2.0

f. Biological Properties

WHITE is a mixture of two systemic herbicides, picloram and 2,4-D. It is partially selective in its defoliant and herbicidal action on an array of plant species and is effective, principally, on woody and certain broad-leaved herbaceous plants. Both the picloram and 2,4-D components are relatively ineffective on grasses, bamboos, and other monocotyledonous plants. Forest areas defoliated with WHITE often show an immediate increase in these resistant plants.

Both picloram and 2,4-D are readily absorbed by the foliage. Picloram, apparently, is more easily absorbed by the root system than are 2,4-D and other phenoxy herbicides.

The picloram component of WHITE is more persistent in soils as compared with other chemicals such as ORANGE and BLUE. Microbial decomposition of picloram is limited and losses from soils occur principally by leaching and some photodecomposition. At rates used for defoliation it may persist in some soils for 1 year or more.

2. Toxicology

Toxicity data have been collected for the components 2,4-D and picloram and for the mixture WHITE. Picloram is extremely low in toxicity; the LD_{50} for acute oral toxicity in rats is 8,200 mg/kg; for sheep and cattle it is 488 to 650 mg/kg.

For Tordon 101, or WHITE, the acute oral LD_{50} for rats has been reported as 3,080 mg/kg; for sheep 2,000; and for cattle 3,163.

In a feeding test on cattle, 97.7% of the administered picloram was recovered unchanged in the urine; no picloram was detected in milk.[20,*]

Median tolerance limits of fish to Tordon 101 ranged from 64 ppm for fathead minnow to 240 ppm for brook trout.

Toxicological studies conducted by Edgewood Arsenal and Dow Chemical Company indicate that a single direct exposure to a spray of WHITE, at prescribed rates, would not constitute a hazard to the skin or a systemic hazard by inhalation.

The chemical is considered nontoxic and not hazardous to humans, animals, and fish.

3. Handling

Only ordinary precautions are recommended for handling WHITE, as for any common agricultural chemical. It may be mildly irritating to skin and eyes on prolonged contact. Contaminated clothing should be washed before reuse. Spillage on the skin should be rinsed with clear water.

WHITE is safe for personnel and animals on sprayed areas at the time of or following application. WHITE may be used in spray equipment following or preceding ORANGE, as discussed in Section III,A,3.

WHITE should be thoroughly flushed and rinsed from spray systems prior to use of agent BLUE to avoid precipitation of the residual 2,4-D, as sodium salt, by the sodium cacodylate of BLUE. Tanks and spray systems should be thoroughly flushed with water before a change of agents or anticipated disuse.

4. Methods of Disposal

Loading and storage areas subject to chemical spillage may be partially decontaminated by repeated washing with ammonia water and flushing with clear water. Runoff water from such flushing operations should be diverted to settling basins or restricted areas not subject to overflow on cropland. Picloram in WHITE is persistent in spray equipment and containers or in soil, thus full decontamination of equipment or areas subject to spillage is extremely difficult. A vigorous regimen of soap and water, ammonia water, and clear water rinses and flushings is necessary. Equipment used for WHITE should not be used for other purposes such as fertilizing or applying insecticides.

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* Weimer, J.T.; et al. September 1967. Toxicological studies relating to use of WHITE as a defoliant. U.S. Army Edgewood Arsenal, Maryland. Unpublished data.

5. Effectiveness as a Defoliant

WHITE and its primary component picloram are selective systemic herbicides. They are effective principally on broad-leaved herbaceous plants and particularly on woody plants at relatively low rates of application. Most grasses and monocotyledenous plants are resistant to picloram.

Herbicidal action on woody plants is relatively slow, and full defoliation may not occur for several months after spray application. Temperate zone conifers are susceptible to picloram but exhibit a delayed defoliation response.

6. Effectiveness as an Anticrop Agent

WHITE has not been recommended for crop destruction due to its persistence in soils for periods of 1 year or more. Both picloram and 2,4-D, the active components of WHITE, are extremely effective herbicides on broad-leaved crop species. Applications of as little as 0.05 to 0.10 lb./acre of picloram have caused substantial yield reductions of garden beans, soybeans, Irish potatoes, peanuts, sweet potatoes, and others.[21] Variable results have been obtained on cereal crops, but in general the cereals and grasses are resistant to picloram and WHITE. A notable exception is that wheat yields are eliminated by WHITE applied at 2.0 lb. active ingredients per acre. Soybeans, cotton, and tomatoes are extremely sensitive to picloram. Seedlings of these crops show visible symptoms of herbicide effect with residual amounts of less than six parts per billion of picloram in the soil. Tomatoes may be killed with sprays containing 1.0 ppm of picloram, whereas wheat, rice, and corn tolerate more than 2,400 ppm picloram applied as a foliage spray.[22]

D. CANDIDATE AGENTS

Several chemicals are being developed as candidate agents or have been subjected to preliminary testing under field conditions. This group includes Modified ORANGE, a proposed defoliant; bromacil and Tandex as soil-applied herbicides for control of grasses and broad-leaved vegetation; and Kenapon, a liquid formulation of dalapon, suggested for grass control in RVN by the Dow Company. Monuron (Telvar) and diuron (Karmex) are additional soil-applied herbicides that have been used for grass and total vegetation control.

1. Modified ORANGE

The name Modified ORANGE has been given to a mixture of ORANGE and isooctyl ester of picloram, proposed as a broad-spectrum defoliant.

One gallon of Modified ORANGE contains 1 lb. of picloram as isooctyl ester and 3.1 lb. of 2,4-D and 3.2 lb. of 2,4,5-T as n-butyl esters. An equivalent field mixture of Modified ORANGE may be prepared by blending one part of Tordon 40, containing 4 lb. of picloram per gal, with three parts of ORANGE. The blending may be accomplished by pumping the mixture through at least two recycles in a tank and pump system. Approximate cost is $9.50/gal.

Limited tests of Modified ORANGE under tropical and temperate conditions have shown it to control a broader spectrum of species than either separate component, with a somewhat more effective and longer-lasting defoliation response than ORANGE alone when applied at equivalent 3-gal volumes.

2. Soil-Applied Herbicides

Soil-applied herbicides have been used extensively in the US for vegetation control in industrial areas, railway embankments, rights-of-way, and other areas where complete vegetation control is desired. These materials are particularly effective for the control of perennial grasses and should be considered for use on base camp perimeters, mine fields, ammunition storage areas, and other sites requiring control of grasses and woody vegetation. Soil-applied herbicides may be used in liquid sprays or as granular or pelleted formulations. Most of the chemicals are available as wettable powders requiring relatively large volumes of water and agitation for liquid spray application. The chemicals are absorbed through the root system and are dependent upon effective rainfall and available soil moisture for action in vegetation control.

a. Bromacil

Bromacil, 5-bromo-3-sec-butyl-6-methyluracil, is an odorless, white crystalline solid, soluble in water (815 ppm at 25 C), stable noncorrosive, and nonvolatile.

Bromacil is relatively nontoxic to man, wildlife, and fish. Acute oral LD_{50} for rats is 5,200 mg/kg. It presents no hazard in handling except minor skin irritation on prolonged contact.

Available formulations include: Hyvar X, 80% wettable powder; Hyvar 10P, pellets containing 10% bromacil; and Nalkil 4B, liquid formulation containing 4 lb./gal bromacil.

Experimental granular formulations containing 85% active bromacil have been prepared for study by Fort Detrick. The basic chemical, bromacil (Hyvar), is produced by E.I. du Pont de Nemours & Co., Inc.

Bromacil is one of the most effective soil-applied herbicides suitable for control of perennial grasses and woody plants. Under temperate conditions bromacil at 12 to 25 lb./acre given effective control of most perennial grasses. Under tropical conditions 30 lb./acre or more may be required for grass and woody plant control.

Wettable powder formulations such as Hyvar X are suitable principally for ground spray application at high volumes (100 gal/acre or more). Tank sprayers used for wettable powder suspensions should be equipped with mechanical agitation. Available liquid formulations of bromacil are designed for industrial use in high-volume sprays. Aerial spray applications of these liquid formulations require a minimum volume of 10 gal/acre for use rates of 30 lb./acre of bromacil. Approximate cost is $5.70/lb.

b. Tandex

Tandex, m-(3,3-dimethylureido)phenyl-tert-butylcarbamate, (Niagara 11092), manufactured by Niagara Chemical Division of FMC Corporation, is a white crystalline solid, relatively soluble in water (325 ppm at 25 C), stable, noncorrosive, and nonvolatile.

Tandex is relatively nontoxic to all forms of animal life. Acute oral LD_{50} for rats is 3,000 mg/kg. It is nonirritating to animals and presents no hazard in handling.

Available formulations include 80% wettable powder and 16% granular formulation.

Tandex is a new soil herbicide capable of effective control of perennial grasses and broad-leaved herbaceous and woody plants at rates comparable to those for bromacil. Unlike bromacil, which is absorbed only through the root system, Tandex is equally effective as foliage sprays or soil applications. Under temperate conditions, applications of 15 to 25 lb./acre of Tandex have given long-term control (1 year) of perennial grass and other vegetation. Information from tropical areas is incomplete, but Tandex appears to be equivalent to bromacil in degree and duration of vegetation control. In tests to date, Tandex appears to control a greater number of broad-leaved plants than bromacil. Approximate cost of 80% wettable powder is $5.75/lb.

c. Monuron (Telvar)

Monuron, 3-(p-chlorophenyl)-1,1-dimethylurea, produced by E.I. du Pont de Nemours & Co., Inc., is an odorless, crystalline solid, highly soluble in acetone and slightly soluble in water (230 ppm at 25 C), noncorrosive, stable in storage, and subject to minimal loss by photodecomposition.

Monuron has low toxicity. Acute oral LD_{50} to rats is 3,600 mg/kg.

Monuron has been used for selective weed control at low rates (1 to 5 lb./acre) and for general vegetation control at 16 to 48 lb./acre or more. Resistant perennial grasses may require more than 50 lb./acre and additional treatments for long-term control.

In general, bromacil is preferred to monuron for perennial grass control because of its lower use rate and its greater availability in heavy soils. Monuron is readily adsorbed by clay soils and higher use rates are required than in sandy soils.

Monuron is suitable only for ground spray application because of its high use requirement and availability only as a wettable powder. Approximate cost is $2.85/lb.

d. Diuron (Karmex)

Diuron or Karmex, 3-(3,4-dichlorophenyl)-1,1-dimethylurea, produced by E.I. du Pont de Nemours & Co., Inc., is an odorless white crystalline solid, only slightly soluble in water (42 ppm at 25 C), but readily soluble in acetone and organic solvents.

Diuron is similar to monuron in having low toxicity to man and animals. Acute oral LD_{50} to rats is 3,400 mg/kg.

Diuron is available as 80% wettable powder (Karmex) and as Karmex DL, a liquid formulation containing 2.8 lb. of diuron/gal.

Because of its extremely low solubility, diuron has a long residual action in the soil, especially with high rainfall. It is effective for grass and broad-leaved herbaceous plant control at 16 to 48 lb./acre. Diuron has been used at lower rates for selective weed control. It is suggested for mixtures with bromacil and as a maintenance treatment following bromacil.

Its high dosage requirement limits the feasibility of using diuron in aerial application. Approximate cost is $2.95/lb.

3. Dalapon (Kenapon)

Dalapon, 2,2-dichloropropionic acid, manufactured by Dow Chemical Company, is a colorless liquid, highly soluble in water and alcohol, and readily decomposed by soil bacteria.

Dalapon is low in toxicity to man and wildlife. Acute oral LD_{50} to rats is 7,570 to 9,330 mg/kg. Dalapon may cause moderate skin irritation on prolonged contact but presents no handling problem.

Dalapon is available in two primary formulations: 85% sodium salt, a water-soluble powder; and diethylene glycol ester (Kenapon), a liquid formulation containing 5 lb. dalapon/gal.

The liquid formulation, Kenapon, has been suggested by the Dow Company for military use for control of perennial grasses. Dalapon has both contact and systemic effects and causes a rapid desiccation of topgrowth of grasses. Suggested rates of application are 20 to 25 lb./acre (4 to 5 gal/acre) with repeat treatments at 6-week intervals or at appropriate periods to control regrowth.

Kenapon is a formulation of dalapon suitable for aerial application at low volumes. Both Kenapon and the sodium salt may be used in ground spray equipment. Approximate costs are $0.63/lb. for dalapon and $6.10/gal for Kenapon.

IV. SELECTION AND TEST EVALUATION OF CANDIDATE AGENTS

A. CRITERIA

In the selection of candidates and the development of improved defoliant agents and systems, the following criteria are recognized:

1) Broad spectrum of activity

The agent should be active on many kinds of plants, with emphasis on woody species. A continued search is being made for a universal defoliant effective on all kinds of plants. ORANGE and WHITE, currently in use, exhibit selectivity in species response and are notably ineffective in the control of grasses and other monocotyledenous plants.

2) Rapid in action

Defoliation in 1 to 3 days after application is an accepted goal for improved defoliants. Current defoliation agents in use are primarily systemic herbicides and exhibit a delay in attainment of full defoliation. WHITE is notably slower than ORANGE in causing defoliation under tropical conditions. In coniferous forest vegetation (e.g., Canada) defoliation with WHITE or picloram is not fully achieved until the growing season following spray application.

3) Suitable for application with air or ground equipment

Selected agents are preferably liquids with high concentrations of active ingredients. Physical properties of the agent such as viscosity, density, flammability and compatibility with solvents and components of dissemination systems should permit low-volume application of appropriate droplet or particle size at minimal pressures from available spray devices.

4) Nontoxic to man and animals

In the search for new or improved candidates, compounds of moderate toxicity may be included in the initial screening programs because highly promising candidates may be modified to minimize toxicity. Selected agents should present minimal toxicity to man, domestic animals, and all forms of fish and wildlife both at the time of and subsequent to application. Preference is given to chemicals that decompose readily without toxic or harmful residues in soil or treated vegetation.

5) Stable in storage

Selected chemicals should remain stable under storage conditions ranging from freezing temperatures to tropical heat and high humidity. Preference may be given to concentrated liquids that retain flowable characteristics under a wide range of temperatures. Dry herbicides that absorb moisture from the environment are to be avoided. However, extremely stable chemicals resistant to microbial or hydrolytic decomposition on contact with the soil present disadvantages where a short-term response is needed.

6) Effective in low dosage

Under optimum conditions, the selected defoliant agent should be effective at minimal dosage rates consistent with the requirements for adequate volume coverage of the target vegetation. In general, the volume requirements for effective defoliation may be less for a growth regulator or systemic herbicide in comparison with a contact herbicide or desiccant. Initial screening programs with seedling plants utilize dosage levels of 0.1 and 1.0 lb/acre as a basis for selection of active compounds.

7) Noncorrosive

Selected agent should preferably be noncorrosive to storage containers, dissemination systems, and aircraft or mobile equipment used in application. The corrosive action of an agent may restrict its use or require rigid maintenance schedules to minimize damage or deleterious effects on equipment.

8) Low in cost

Cost is of secondary importance in the selection and improvement of agents. Effectiveness and utility of the agent should be given first consideration.

9) Readily available or capable of manufacture

Selected agents should be producible in large quantities at an acceptable cost.

B. SCREENING AND FIELD TESTING CANDIDATE AGENTS

Fort Detrick has tested and evaluated 26,000 chemical compounds, including every herbicide that has been marketed in the United States as well as many from foreign sources.

A continuing program of research on biological activity of chemicals has shown that many chemical compounds exhibit growth regulating, desiccant, or herbicidal activity but few satisfy military agent criteria. More than 200 chemicals are now marketed commercially as herbicides for agricultural and industrial use. These represent selections from many thousands of chemicals investigated by the chemical industry and private and government research.

At Fort Detrick, chemicals with known biological activity and new candidates are studied in the continuing search for improved vegetation-control agents. Recently, 7,000 new chemicals for testing were obtained from Walter Reed Institute of Research.*

Initial screening is conducted on seedling plants (7 days old) of six species: Black Valentine beans, soybeans, morning glory, radish, oats, and rice. Evaluations are made of desiccant, herbicidal, and growth-regulating responses over a 2-week period from foliar spray applications at 0.1 and 1.0 lb./acre. Numerical ratings applied to each species on a 4-point scale as no, slight, moderate, or severe responses give a total maximum score of 24 points. Ratings of the three principal agents in this primary screening program are as follows:

	0.1 lb./acre	1.0 lb./acre
ORANGE	20	20
WHITE	13	20
BLUE	10	22

Both ORANGE and WHITE are less effective on grasses than broad-leaved plants and the ratings of 20 at 1 lb/acre reflect the limited responses on oats and rice of the six plants in this test.

High-rating chemicals in the primary screening test are subjected to an intermediate screening for defoliation activity on 14-day-old Black Valentine bean plants at 0.1 and 1.0 lb/acre. Black Valentine bean has been selected as a test plant for defoliation effect because of its characteristic leaf abscission. Typical responses of the three agents in this screening test are as follows:

	0.1 lb./acre	1.0 lb./acre
ORANGE	Moderate desiccation	Death at 10 days; growth regulator effects
WHITE	Death at 14 days; growth regulator effects	Death at 14 days; growth regulator effects
BLUE	Slight desiccation	Death at 14 days

Candidate chemicals showing high activity in the Black Valentine bean defoliation screen then are subjected to evaluation for desiccation and herbicidal response on eight to 10 woody species under greenhouse conditions. Species used in this test at Fort Detrick include: eastern hemlock, Norway spruce, Chinese elm, black locust, red maple, pin oak, California privet,

* Division of Medicinal Chemistry, Walter Reed Army Medical Center, Washington, D.C.

Scotch pine, pittosporum, and eucalyptus. Foliar sprays are applied to 2- to 3-year-old seedling plants at rates of 1, 5, and 10 lb./acre of active ingredient or acid equivalent. In the case of ORANGE, WHITE, and BLUE, application rates are based on weight of acid equivalent rather than the total ester or salt in which the chemical is formulated. Representative data for these three agents on the number of species (of a total of 10) showing extreme desiccation or kill and defoliation at 30, 60, and 90 days follow:

	ORANGE			WHITE			BLUE		
	1	5	10	1	5	10	1	5	10
Desiccation	1	2	4	ND	1	ND	2	5	7
Kill and defoliation									
30 days	3	3	3	2	4	5	1	1	1
60 days	1	1	ND	2	1	3	ND	ND	ND
90 days	1	ND	3	1	1	1	ND	ND	ND

The primary responses of ORANGE and WHITE as herbicides and that of BLUE as a desiccant are evident in these ratings.

Following initial laboratory and greenhouse screening programs, chemicals selected as potential anticrop agents are subjected to field screening and testing on several major crop species. Promising defoliants and herbicides are evaluated in a series of field tests on native vegetation at CONUS and OCONUS sites representing various temperate and tropical plant types.

1. Field Tests of Chemicals on Crops

Evaluations of chemicals on specific crops are made in replicated tests at three dosage rates using a logarithmic sprayer or knapsack sprayer. Seasonal responses are obtained by treatment at two or three stages of growth. Effective rates of application for control of selected crops by the standard and candidate agents listed in Section III are as follows:

	Rate, lb./acre
Rice	
Tandex	0.5
Bromacil	0.5 to 1
BLUE	0.5 to 1
Diuron	2 to 4
Wheat (winter)	
WHITE	2 to 4
Picloram ester	2 to 4
Bromacil	2 to 4
Tandex	2 to 4
BLUE	2 to 4
Sugarcane	
Bromacil	5 to 15
Tandex	5 to 15
Corn	
BLUE	1 to 2
Dalapon	2 to 4
Bromacil	4
Tandex	4 to 6
Diuron	4 to 8

	Rate, lb./acre
Potatoes	
Picloram ester	C.5
WHITE	1
ORANGE	4 to 8
Soybeans	
Picloram ester	0.25
WHITE	0.25
ORANGE	0.5 to 1
Tandex	1 to 2
"romacil	1 to 2
Castorbeans	
Picloram ester	0.5
ORANGE	0.5
WHITE	1
Manioc	
WHITE	0.2
Picloram ester	0.5
ORANGE	1

2. Field Tests of Defoliants

Initial field testing of defoliants on native woody vegetation has been conducted by Fort Detrick personnel with a vehicle-mounted high-lift boom capable of overhead spray application on plots ranging in size from 20 by 20 feet to circular areas 50 feet in diameter. Subsequent R&D tests have been conducted with aerial dissemination systems, principally the HIDAL, using H-19 and H-34 aircraft and the UH-1B/D helicopter-mounted sprayer, with 200-gal tank, developed by AGRINAUTICS. Both helicopter and fixed-wing agricultural aircraft spray systems also have been utilized for CONUS and OCONUS tests. Application volumes in the test program have varied from 1 to 10 gal/acre.

Field tests of candidate defoliants are designed to evaluate such variables as rates, volume of application, season, and vegetation composition. Three rates of application are usually employed to develop dosage-response data. Evaluation procedures vary with the objectives and intensity level of the test program; these may include determinations of:

1) Defoliation on degree of canopy removal by one or more of the following:

(i) visual estimates of overall defoliation; (ii) estimates of defoliation based on repeated observation of individual marked plants of important species; species data may be summed for the vegetation type or test site; (iii) percentage reduction of vertical obscuration as determined by repeated vertical photographs at permanent photo stations; (iv) percentage increase in horizontal visibility based on changes in obscuration of targets at selected distances from a central observation point; and (v) aerial photography with color or camouflage detection film.

2) Desiccation or contact injury from visual overall or individual species ratings.

3) Plant kill, based on overall visual estimates or composited species ratings from sampled individuals.

Defoliation and desiccation may be evaluated periodically to determine percentage and duration of response. Plant kill determinations should be made after one complete growing season has elapsed following treatment.

3. Parameters for Effective Defoliation

Available data from aerial application tests at several CONUS and OCONUS locations are presented in the following tables to illustrate the effects of variables such as vegetation type, vegetation structure, rate, and season of application of agent on defoliation response.

a. Rate of Application

Under tropical conditions, applications of ORANGE and WHITE at 3 gal/acre appear to give optimum defoliation (Tables 1, 2, and 3). Tests with ORANGE over the range of 1.0 to 6.0 gal/acre showed increased defoliation with higher rates of application. Under temperate zone conditions, the 3 gal/acre rate of WHITE gives effective long-term defoliation (Table 4).

Increasing the rate of application of BLUE in excess of 9 to 12 lb./acre did not appreciably increase the efficiency of defoliation (Table 5).

b. Season of Application

Tests of ORANGE and its predecessor PURPLE in Thailand showed that applications were more effective during the rainy or growing season than in the dry season (Table 2). A higher rate of application may partially compensate for the difference in seasonal response. In the same tests, cacodylic acid or BLUE showed no difference in defoliation with season of application.

TABLE 1. DEFOLIATION RESPONSES FROM ORANGE IN TROPICAL FOREST SITES[33]

Location and Rate in gal/acre	Defoliation at Period Indicated, % 1 mo	3 mo	6 mo	9 mo	12 mo
Loquillo, Puerto Rico:					
tropical rain forest	April 1966 Application				
1.5	61	65	52	-a/	38
3.0	73	79	66	-	55
6.0	75	91	71	-	61
	October 1966 Application				
3.0	46	62	75	-	-
Hilo, Hawaii:					
ohia, tree fern forest	December 1966 Application				
3	45	60	62	58	55
Kauai, Hawaii:					
ohia, guava, java plum	December 1967 Application				
3	71	84	80	-	-
Thailand:					
dry evergreen forest	May 1964 Application				
3	-	90	66	50	30
	September 1964 Application				
3	40	57	60	45	32
	December 1964 Application				
3	15	52	52	37	27

INTERPRETATION OF TABLE 1: (i) Significant defoliation may occur at 1 month after spray application. (ii) Maximum defoliation usually occurs at 2 to 3 months after spray application. (iii) Regrowth of vegetation occurs in 9 to 12 months as shown by the decrease in defoliation ratings.

a. - = no data.

TABLE 2. DEFOLIANT EFFECTIVENESS OF ORANGE[a/] IN TROPICAL FOREST VEGETATION AS RELATED TO RATE, SEASON OF APPLICATION, AND DENSITY OF FOREST CANOPY[b/]

Spray Deposit, gal/acre	Maximum Defoliation, %			
	Rainy Season Application Canopy		Dry Season Application Canopy	
	Single	Multiple	Single	Multiple
3.0	88	75	82	67
2.5	79	66	71	61
2.0	76	59	64	54
1.5	76	52	58	48
1.0	76	49	52	42

INTERPRETATION OF TABLE 2: (i) Greater defoliation is achieved under all conditions at the higher rates of application of 2.5 to 3.0 gal/acre. (ii) Greatest defoliation occurs in vegetation types with a light or moderate density typical of a single canopy. Multiple layers of canopy foliage interfere with penetration of spray to lower vegetation. (iii) Treatment during the dry season reduces the maximum response especially at the lighter dosage rates. As a systemic herbicide, ORANGE is more effective during periods of active vegetative growth. (iv) The data may also indicate that greatest overall effects may be obtained from two 1-gal/acre treatments, with the second at the peak of defoliation from the first application.

a. Tests included ORANGE and its predecessor PURPLE.
b. Data based on OCONUS defoliation tests in Thailand.[14]

TABLE 3. DEFOLIATION EFFECTIVENESS OF ORANGE IN TROPICAL RAIN FOREST OF PUERTO RICO AS RELATED TO RATE OF APPLICATION[33]

Location and Rate in gal/acre	Defoliation at Period Indicated, %			
	1 mo	3 mo	6 mo	1 yr
Luquillo National Forest, April 1966				
1.5	61	65	52	38
3.0	73	79	66	55
6.0	75	91	71	61

INTERPRETATION OF TABLE 3: (i) Effective defoliation was obtained at 1 month after application at all rates. (ii) Increasing the rate of application gave higher rates of defoliation. However, over the period of evaluation, the increased defoliation at 6.0 gal/acre was not proportional to the increase in cost and logistics burden compared with the 3.0 gal/acre rate.

TABLE 4. REPRESENTATIVE DATA ON DEFOLIATION AND VEGETATION CONTROL WITH ORANGE AND WHITE ONE YEAR AFTER TREATMENT[a]

Location and Vegetation Type	Vegetation Control at 1 Year, %	
	ORANGE	WHITE
New Brunswick, Canada, 1967: birch, maple, aspen, spruce, fir	51	82
Florida, 1967: water oak, magnolia, sweet gum, holly	54	-[b]
Georgia, 1967: bluejack, turkey, and post oaks	57	72
Arkansas, 1967: post oak, hickory, winged elm	63, 70	82
Kauai, Hawaii, 1967: ohia, melastoma, lantana, guava	56[c]	71
Thailand, 1964: tropical dry evergreen forest	36[d]	70[d]

INTERPRETATION OF TABLE 4: (i) In both temperate and tropical forests, applications of ORANGE and WHITE at 3 gal/acre do not provide for complete defoliation at 1 year following application. (ii) WHITE appears to be more effective than ORANGE in defoliation on a long-term basis. However, peak defoliation from WHITE develops much later than that from ORANGE application.

a. Applications at 3 gal/acre.
b. No data.
c. Evaluation at 9 months.
d. Application of ORANGE at 2.5 gal/acre; WHITE application consisted of 2.3 lb./acre of picloram + 5.3 lb./acre of 2,4-D (picloram equivalent to 4.6 gal/acre of WHITE).

TABLE 5. DURATION OF DEFOLIATION OF TROPICAL VEGETATION WITH AERIALLY APPLIED BLUE[a]

Location, Species, and Rate in lb./acre	Defoliation, %, at Indicated Days after Treatment 7	14	30	60	180
Las Marias, Puerto Rico, 1967:					
semi-evergreen forest					
12	51	60	70	57	43
Kauai, Hawaii, 1967:					
gauva, ohia, Java plum, staghorn fern					
9	37	45	54	51	25[b]
12	40	56	62	54	26[b]
15	40	56	59	57	26[b]
Thailand, 1964-1965:					
tropical dry evergreen forest					
3.4	15	42	52	37	15
6.0	30	55	65	43	25

INTERPRETATION OF TABLE 5: (i) Maximum defoliation of tropical vegetation occurs at 2 to 4 weeks after application of BLUE. (ii) BLUE causes short-term defoliation. Substantial regrowth occurs by 60 days or later as shown by marked reductions in defoliation ratings at 4 to 6 months. BLUE acts as a desiccant rather than a systemic herbicide as ORANGE and WHITE.

a. Rate of 9 lb./acre is equivalent to 3 gal/acre of BLUE or Phytar 560G.

b. At 120 months.

c. Single- Versus Multiple-Canopy Vegetation

Structure of vegetation influences the degree of coverage and penetration of spray deposit in aerial application. Data on defoliation response in single and multiple canopy in Table 2 show that somewhat greater defoliation was obtained in forest types with a single versus multiple canopy.

In multiple-canopy vegetation, repeat spray application may be required to obtain adequate defoliation of dense undergrowth after the upper foliage canopy has been reduced from the initial spray treatment.

d. Vegetation Type and Species Composition

Overall defoliation response will be affected by the species composition and type of vegetation. Species vary widely in their response or susceptibility to the systemic herbicides ORANGE and WHITE, and the long-term effectiveness of defoliant treatments will be influenced by the proportion of resistant species in the vegetation complex.

Temperate zone vegetation appears to respond somewhat better to agents ORANGE and WHITE than tropical vegetation (Table 4). A notable difference in effectiveness between the two agents ORANGE and WHITE is in the greater response of coniferous evergreen types to picloram or WHITE than to ORANGE. In Vietnam, the nipa palm is much more susceptible to ORANGE than to WHITE.

V. AERIAL DELIVERY SYSTEMS

A. C-123/MC-1 SPRAY SYSTEM

The first spray system employed in Vietnam by the USAF was developed at Langley AFB, Virginia, for dissemination of liquid insecticides. The system consisted of the Fairchild C-123 aircraft, the modified MC-1 (Hourglass) spray device (1,000-gal tank, 10-hp gasoline engine, pump, and piping) with spray booms on each wing extending from the wing tip to the outboard engine nacelle. Each spray boom was 1.5 inches in diameter and contained 42 teejet nozzles. The system was capable of spraying PURPLE at a rate adequate to deposit 1 gal agent per acre. Subsequent to use of the system, the OSD/ARPA evaluation team made a series of recommendations that included:[13]

1) Modify the spray system to provide for deposit of 1.5 gal/acre in a spray having a MMD of 300 μ.

2) Apply 3 gal of PURPLE per acre on upland forest targets (two passes at 1.5 gal/acre each).

3) Develop a system capable of depositing 3 gal/acre on target.

1. Modification and Calibration

During the spring of 1962, ARPA sponsored a test and evaluation program on various spray configurations of the C-123/MC-1 system as well as work on the USN HIDAL (Helicopter, Insecticide Dispersal Apparatus, Liquid) spray device.[24] The second, major modification of the C-123/MC-1 system was tested and evaluated at Eglin AFB, Florida, in 1963 (Fig. 2). Concurrently, additional studies were accomplished on the HIDAL system and on a prototype USN FIDAL (Fixed-Wing, Insecticide Dispersal Apparatus, Liquid).[25] The results of the 1962 spray trials were evaluated and a configuration was described that would produce an effective swath of approximately 300 feet with a deposit of 1.5 gal PURPLE per acre in a spray having an MMD of 293 μ (release altitude 150 feet; airspeed 130 knots). The testing during 1963 was an extension of the 1962 effort on various modifications of the C-123/MC-1 system to achieve 3 gal/acre deposits of PURPLE. Major changes in the test system included: two 20-hp engine-pump combinations per unit as the power source; an added tail boom; all new spray booms 3 inches in diameter. A total of 110 ½-inch check valves were installed in the three booms. Early in the test program the 3-inch wing booms proved to be unsatisfactory and were replaced with booms 1.5 inches in diameter. Conclusions from the results of the tests were:

1) Three-gal/acre deposits can be achieved on swaths 240 feet wide when spraying at an airspeed of 130 knots at 150-foot altitude.

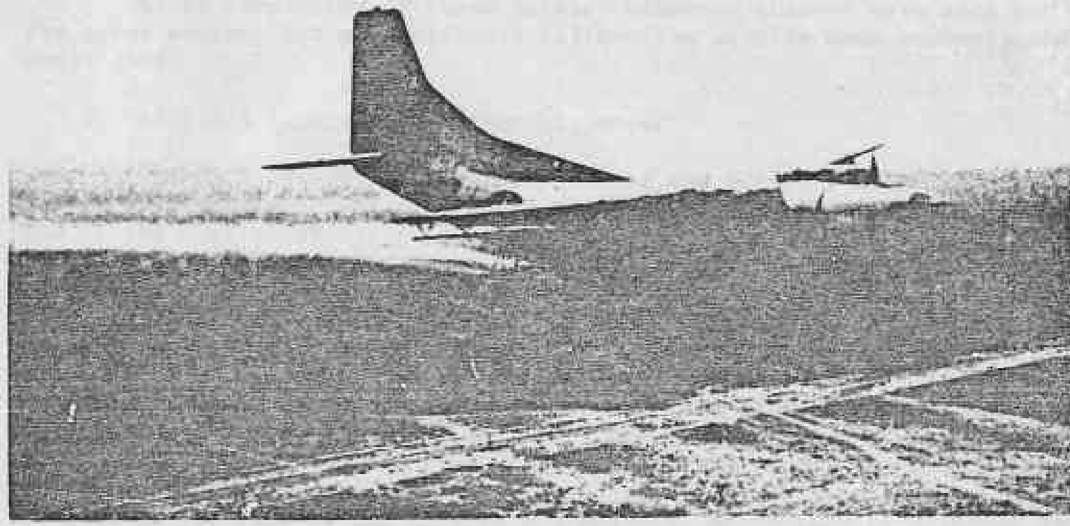

FIGURE 2. UC-123B Aircraft with MC-1 Spray System as Modified in the 1963 Eglin AFB Calibration Trials.

2) Two 20-hp pumps are needed to achieve a required flow rate of 430 gal/min of PURPLE.

3) Using only the wing booms, 2 gal/acre is the maximum practical deposit possible; using all booms, 3-gal deposits may be obtained.

The recommendations included replacement of the 10-hp engines in the operational systems with the more versatile 20-hp units.

After completion of these trials, numerous changes were made in the spray system, but no additional calibration studies were accomplished until 1968.

2. A/A45Y-1 Internal Defoliant Dispenser

The USAF development and adoption of the A/A45Y-1 Internal Defoliant Dispenser represents a major step in the evolution of the defoliant system and is the unit currently in use by RANCH HAND (Fig. 3). The A/A45Y-1 defoliant dispenser is a modular spray system for internal carriage in cargo aircraft. The module consists of a 1,000-gal tank, pump, and engine (20 hp) mounted on a frame pallet. An operator's console is an integral part of the unit but is not mounted on the pallet. The C-123 aircraft has wing booms 1.5 inches in diameter and 22 feet long extending from the outboard engine nacelles toward the wing tips. A short tail boom 3 inches in diameter is positioned centrally near the aft cargo door. There are 16 nozzles on each wing boom and eight on the tail boom. The nozzles are check valve bodies with 3/8-inch orifices (no nozzle tips). The system is capable of spraying at the rate of 275 gal/min, which when released at 150 feet altitude at 130 knots airspeed will produce a swath 240 feet wide with a mean deposit of 3 gal/acre in a coarse spray having an MMD of 320 to 350 μ. Spraying time is approximately 3.5 to 4 minutes, which is adequate to dispense 950 gal of chemical on a line about 8.7 statute miles (14 km) in length. In order to achieve predictable deposits, it is recommended that the missions be conducted under inversion to neutral temperature situations and calm wind conditions.

B. HIDAL

In 1961, when testing in Vietnam was proposed, the USN HIDAL was the only known military spray system suitable for use on the H-19 and H-34 helicopters (Fig. 4), then being used by the Vietnamese Air Force (VNAF). The unit had been designed and built by the Disease Vector Control Center, Naval Air Station, Jacksonville, Florida, for dissemination of aqueous solutions of insecticides. One such unit was obtained and was the first spray system put into operation in Vietnam. Later, a total of six HIDAL units were made operational. The device consists of a 200-gal cylindrical fiber glass tank that is positioned inside the cabin; an

FIGURE 3. UC-123K Aircraft with A/A45Y-1 Internal Defoliant Dispenser Used for Defoliation in RVN in 1968 to 1969.

electrically driven, positive displacement pump capable of delivering 25 gal/min, and two spray booms 25 feet long that extend out and back from the fuselage in a delta design. Each boom was equipped with 21 spraying systems teejet nozzles capable of delivering 0.6 gal/min of water at 40 psi pump pressure. During use, a number of deficiencies were made apparent and several components failed or malfunctioned. Equipment modifications were accomplished by NAS, Jacksonville, and the modified unit was tested during 1962 to 1963. The reliability of the system was improved and the test results show: spraying PURPLE, the unit can develop sprays with an MMD of 365 μ in swaths of 190, 160, and 150 feet wide with deposits of 0.5, 1.0, and 1.5 gal/acre, respectively, when flown inwind at 55 knots at an altitude of 100 feet.[25] Extensive use of the system by VNAF was limited by their inability to maintain the units in an operable condition.

C. SELECTIVE AERIAL SPRAY SYSTEM

Troop units in Vietnam were quick to recognize the usefulness of the vegetation-control agents for maintaining vegetation-free perimeter defenses, helicopter landing sites, and destruction of Viet Cong (VC) garden plots. These areas were considered to be too small to justify the use of the RANCH HAND systems; further, the field units felt a need to have their own spray capabilities. A number of jerry-rigged spray devices for use in helicopters were assembled and used. One such unit (SASS) was described in a letter from the Army Concept Team in Vietnam (ACTIV) to six airmobile units. The system was simply constructed with components available in the field and consisted of a 55-gal drum, a pressure unit from a portable flame thrower, connecting hoses, and a length of pipe with drilled holes as a spray boom. The unit could be installed easily in the UH-1B or UH-1D helicopters without modification to the aircraft. The spray boom was tied to the rear skid struts. The unit performed satisfactorily and was recommended for interim use. Another such system consisted of two 55-gal drums welded together end-to-end; a frame was affixed to the bottom for tie-down; large (6 to 8 inches) open tubes fastened to the top on each end of the tank were angled out of the helicopter doors into the airstream and served as ram air orifices to complement gravity flow of the chemical through the spray boom tied to the skids. One other unit utilizes a 400-gal engine shipping container in a CH-47 helicopter and a long boom fastened to the outer edge of the aft cargo door; flow of agent is by gravity feed. Each of these units has satisfied a need for a small spray device for use in available aircraft. The ACTIV letter also described the AGRINAUTICS (then AGAVENCO) spray units that were being used for mosquito control in Vietnam and recommended that such a system be developed for use with vegetation-control agents.

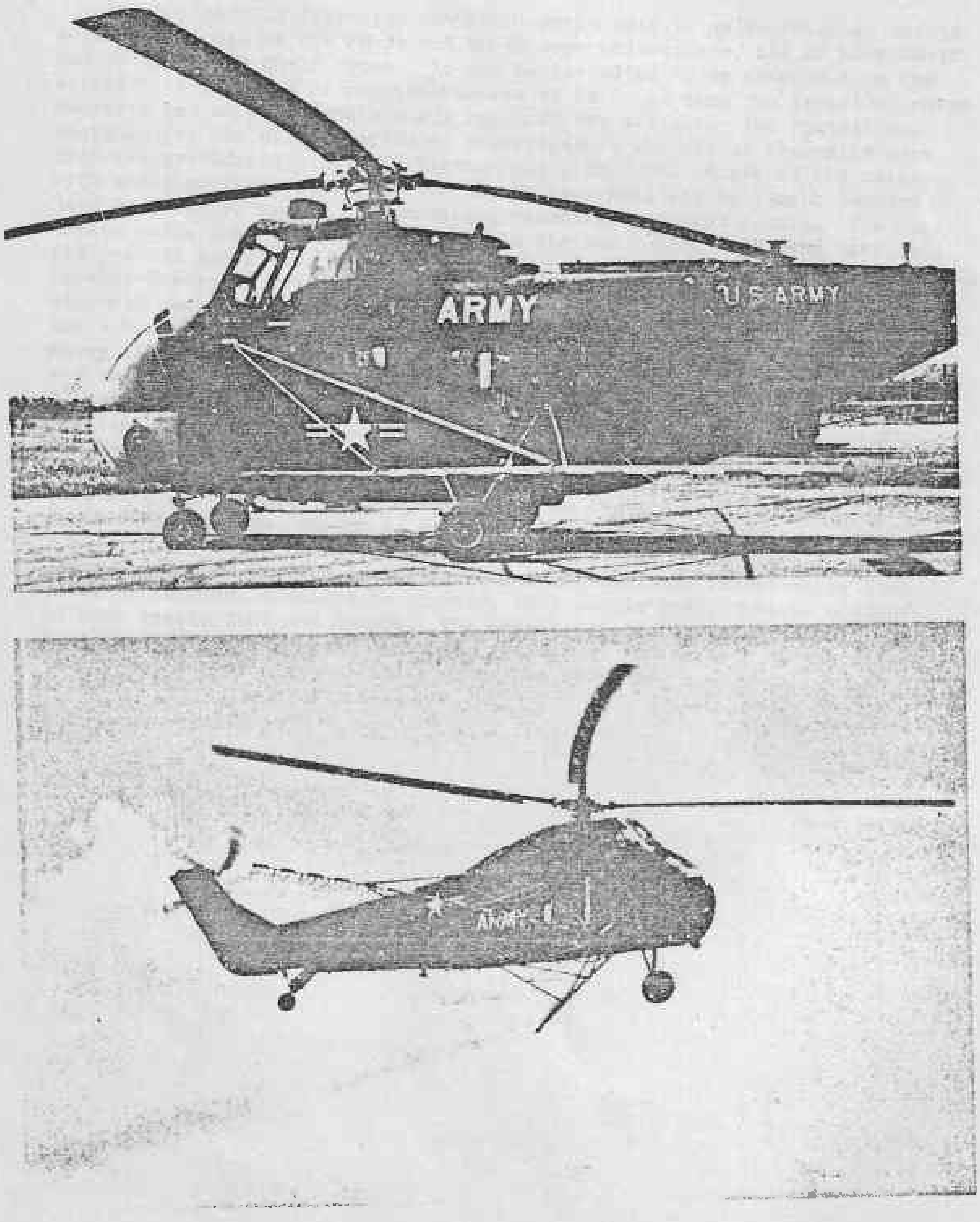

FIGURE 4. HIDAL Unit Used with H-19 (Upper) and H-34 (Lower) US Army Helicopters.

D. UH-1B/D HELICOPTER SPRAY SYSTEM (AGRINAUTICS)

The AGRINAUTICS (formerly AGAVENCO) spray unit is self-contained and is suitable for use in the UH-1B and UH-1D Army helicopters, the US Navy UH-1E, and US Air Force UH-1F types. It can be installed in or removed from the aircraft in a matter of minutes because it is "tied down" to installed cargo shackles and no modifications are required for its use. The sprayer was designed for the dissemination of insecticides, and six of the units were deployed by medical troops in Vietnam early in 1966. Eight of the units, with modifications, were procured by the Army Mobility Equipment Command late in 1967 for use in disseminating vegetation-control agents. The latter units were tested intensively in Vietnam during 1968, and late in the year 21 additional sprayers were ordered for Army use. The Model 3090-2, Sprayer-Pesticide Helicopter Mounted, UH-1B/D is composed of a six-bladed windmill pump drive, spray booms and nozzles, a tank and support structure, and a mechanically operated valve control. The sprayer tank is a 200-gal epoxy structure. The windmill may be manually adjusted on the ground to any selected blade angle from 10 to 90 degrees. The spray boom is 32 feet, 2 inches long and has provisions for nozzles every 4 inches. The unit is operated by manual controls to the flow control valve and a windmill brake. The system has a usable capacity of 195 gal and weighs approximately 200 lb., empty. Limited tests by the manufacturer, on contract with the Army, show that with the maximum pitch setting (1.0) on the windmill, airspeed 50 knots at 50 feet altitude, ORANGE is deposited in a 100-foot swath at a rate of 2.5 gal/acre. The MMD of the spray may be expected to be approximately 300 µ. Users in Vietnam have experienced difficulties in obtaining flow rates of chemical adequate to provide, in a single pass, desired dosages of both agents BLUE and ORANGE. The manufacturer and the US Army Mobility Equipment Command have been advised of limitations in the spray device and corrective modifications may be expected.

VI. GROUND DELIVERY SYSTEMS

A. BUFFALO TURBINE

Engineering development of a ground delivery system for employment of vegetation-control agents has not been accomplished. Various dissemination devices, as field expedients, have been used in Vietnam for control of vegetation on limited areas. The Buffalo turbine is a unit that is representative of one type of disseminator that is capable of disseminating either liquid or dry chemicals and is available from agricultural supply houses in the United States. A number of different models may be obtained: towed or vehicular-mounted; powered by a gasoline engine or from a power take-off assembly; also, various tank sizes are available. One unit that has been in operation in Vietnam since 1961 consists of a trailer-mounted, 100-gal stainless steel tank with agitator, pump, turbine fan, and air-cooled gasoline engine. In operation, the turbine fan serves to generate a high-volume, high-velocity airstream that is projected through a somewhat restricted orifice. Using an available fishtail nozzle, the machine will develop an air blast of a velocity up to 150 mph at 10,000 ft^3/min volume. The chemical injected into the air blast is "shot" at the foliage. Because the materials become finely atomized, care is taken to avoid drift damage. The Buffalo turbine has been useful for roadside spraying and applications on perimeter defenses.

B. MITY-MITE

The Mity-Mite back pack sprayer-duster was introduced into Vietnam for study as a possible means of forcing riot-control agents throughout enemy tunnel complexes. The device was developed by the Buffalo Turbine Co. and operates on the same principle as their larger units. The unit weighs 21 3/4 lb. and consists of a Homelite engine, blower assembly, tank, discharge equipment, and pack frame. The tank capacity is 0.5 ft^3 of dust or 3.5 gal of liquid. In operation, the unit will spray at the rate of 1 gal/min in an airstream of 185-mph velocity and 450 ft^3/min volume (at the hand-held nozzle). The Mity-Mite is suitable for disseminating liquid or dry chemicals for the control of plants in small garden plots and/or seedbeds.

C. POWER-DRIVEN DECONTAMINATING APPARATUS

The power-driven decontaminating apparatus (PDDA) is a self-contained spray system mounted on 6 by 6 military vehicles and is intended for employment of decontaminating chemicals for elimination of toxic antipersonnel agents. In the field, the units are used for many purposes, including the dissemination of vegetation-control agents. Several different PDDA models are available in Vietnam and all are adaptable for use on vegetation-control problems. Tank capacities vary among the models and may be 200, 400, or 600 gal; the larger models have power take-off-driven pumps capable of delivering chemicals at the rate of 35 to 60 gal/min at pump pressures up to 800 lb./$in.^2$

Delivery is through two hoses, with adjustable nozzles, located at the rear of the unit. The PDDA units have been used effectively with available chemicals to control vegetation on minefields, perimeter defenses, roadsides, etc.

VII. TARGET VEGETATION IN VIETNAM

A. DESCRIPTION OF FORESTS

The forests of Vietnam have been studied extensively over the past 60 years and the works are well documented in botanical and forestry literature. According to publications prepared by French botanists, there are more than 1,500 species of woody plants in Vietnam and a wide range of forest types.[17] The botanist, taxonomist, and ecologist are concerned with each specific forest formation; for the problem of defoliation, the military in the field recognizes two principal types of forest: (i) upland forests, which include the dense evergreen and fairly dense semi-evergreen types, and (ii) the lowland or mangrove forests. The basis for this simplified classification is the general, overall response of each type to the available vegetation-control agents. The upland forests are made up of complex associations of plants with varying degrees of sensitivity to defoliant agents and present a much more variable target than the mangrove forests that consist of one dominant plant type that is uniformly sensitive to ORANGE. Complete defoliation (100%) of upland forest targets has not been accomplished.

1. Primary Upland Forest

The primary upland forest usually consists of an overstory or dominant canopy made up of trees varying in height and crown size and an intermediate layer or understory of smaller trees (Fig. 5). The two layers together form a dense canopy as seen from the air. The overstory trees may attain a height of 60 to 125 feet in high-rainfall areas; in regions with a pronounced dry season, the dominant species may be somewhat shorter in height and more widely spaced. Woody vines occur commonly in the top of the canopy and form a dense interwoven network.

The understory is made up of shrubs, vines, and smaller trees, ranging in height from 20 to 30 feet. This lower level may consist of bamboo, vines, cane, grass, and rattan, all close together in a tangled mass, hard to traverse, and limiting visibility to a few yards. A few evergreen species are deciduous in areas that have a dry season.

2. Secondary Forest

The secondary forests may have only remnants of the overstory tree canopy but have dense growth of small trees and shrubs. The understory vegetation is dense and difficult to penetrate. The secondary forests may be represented by areas of tropical scrub on abandoned cropland or areas where timber has been removed. These are made up of an assortment of shrubs, vines, and grasses. The shrubs may be 15 to 20 feet tall and are often covered with vines. This type of vegetation affords cover for man, animals, and equipment against observation from the air.

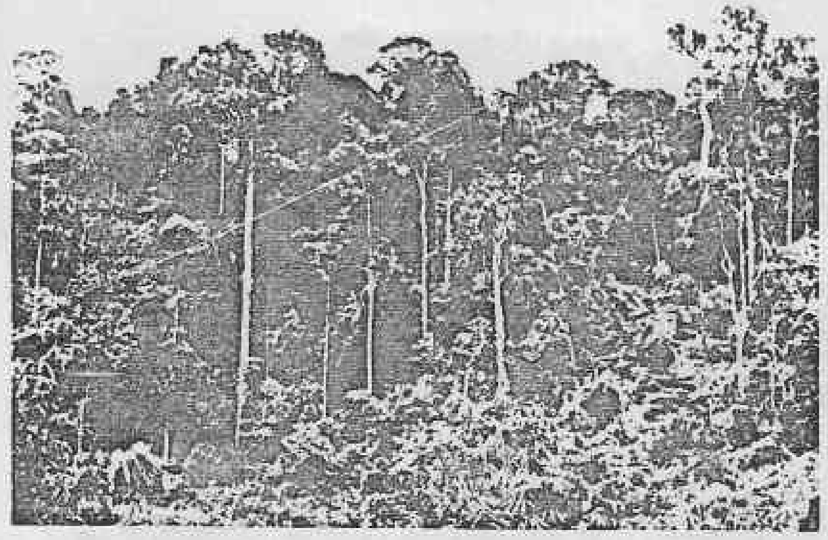

FIGURE 5. Multiple Canopy Jungle or Tropical Evergreen Forest of Southeast Asia.

3. Lowland or Mangrove Forest

Lowland or mangrove forests are of two general kinds: those that grow in standing water, usually within the limits of the mean high tide, and those that grow above the tidal limits but in marshy, poorly drained areas. In either case, dense, pure stands of trees tend to form. In each group, the trees tend to be of the same age, ranging from 25 to 60 feet in height. These trees have prop and aerial roots that impede movement and visibility and crowns that form a continuous canopy that affords protection from air observation. Ground cover is usually lacking, although in places nipa palm, water coconut, and some tall ferns occur (Fig. 6).

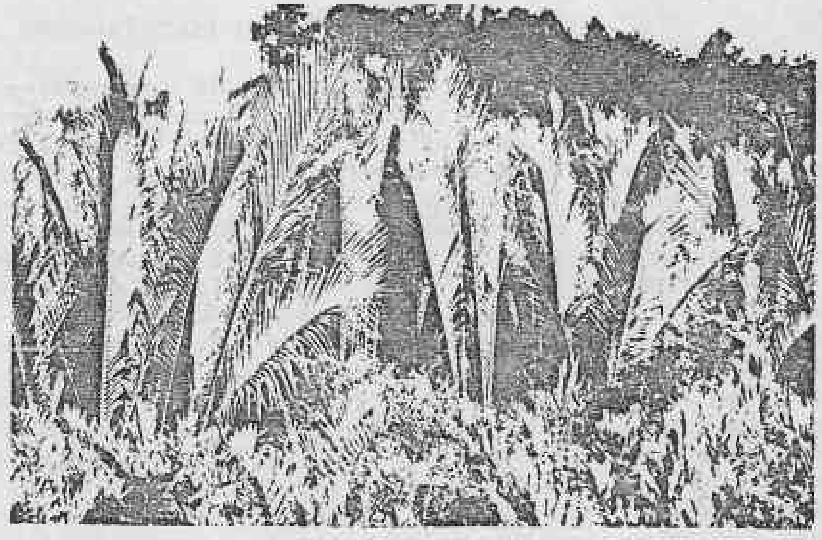

FIGURE 6. Nipa Palm, a Common Associate of Mangrove in the Mekong Delta Region of RVN.

4. Growth Patterns

It must be remembered that many different kinds of trees are in these tropical forests, and each has a different growth cycle and different sensitivity to herbicides, thus making uniform results with defoliants difficult to achieve. In general, the active growing season for upland vegetation starts with the first rains just before the onset of the rainy season, and most of the vegetative growth occurs during the early part of this season. The flowering and fruiting come later in the rainy season or at the start of the dry season. During the dry part of the year, the trees tend to be dormant, but the varying rainfall patterns can vary the periods of active growth. The dormancy factor has a definite influence on the development of effects from an application of the growth-regulator chemicals; defoliation may be delayed until growth is resumed with the onset of the rainy season. The mangrove forest does not exhibit seasonal variations.

B. SINGLE, DOMINANT PLANT TYPE

The largest numbers of spray missions in Vietnam have been carried out on mixed forest vegetation; however, there are a number of prime targets that consist largely of a single, dominant plant type. Outstanding examples include: (i) Nipa palm, frequently found in association with mangrove, provides a dense screen along waterways, and may be controlled successfully only with ORANGE but it responds much more slowly than adjacent vegetation. (ii) Elephant grass is a serious problem in many, if not most, of the so-called "open areas" in upland forests and can be controlled only by BLUE when used at high rates. (iii) Rice is severely damaged or destroyed by BLUE at low rates; the application of 1 gal/acre is more than adequate to cause 100% yield reduction. ORANGE and WHITE are not recommended for use on rice; upward of 5 gal ORANGE per acre are required to damage the plants severely. (iv) Bamboos of various types flourish throughout Vietnam and present a formidable problem when their control is required. Some species may be defoliated by high applications of BLUE, but the plants are not killed and the clumps of stems, alone, provide effective screens. It is felt that the development of a capability to control bamboo effectively may be dependent on use of a soil-applied compound (currently not approved for use in Vietnam). (v) Broad-leaved, annual crop plants, as a type target, may be treated as a single species since they are uniformly killed by the high dosages of ORANGE obtained in Vietnam.

VIII. EMPLOYMENT OF VEGETATION-CONTROL SYSTEMS

A. BLANKET COVERAGE - CROP CONTROL

Prior to the initiation of the defoliation program in Vietnam (1961), a large body of research data on the dissemination of chemical vegetation-control agents was developed by Crops Division, Fort Detrick, in cooperation with USAF and USN. Several experimental, prototype, and developmental spray devices were tested with a variety of aircraft (C-47, F-3D, F-7U, B-17, C-119, B-29). With but few minor exceptions, the test programs had as their objective the ultimate development of blanket-coverage capabilities for large-scale attacks on crop plants. The chemical sprays were released as elevated line sources normal to the prevailing winds; delivery altitudes were varied from 100 to 2,000 feet, and results showed the optimal spray altitude to be 1,000 to 1,500 feet. Further, in recognition that a given mass of material produces the greatest effect when applied as small droplets ($\leq$100 μ), considerable effort was devoted to studies on means of producing high-volume sprays of droplets having an MMD of approximately 175 μ and ground deposits, of what now is known as ORANGE, at 0.1 lb./acre and greater.[a]

The final spray tests with low-speed, propeller-driven aircraft were accomplished during the spring of 1953 at Eglin AFB, Florida. The studies were on the Hourglass unit in B-29 and C-119 aircraft with crosswind spray releases at 3,500- and 5,000-foot intervals at altitudes of 1,000 and 2,000 feet and agent flow rate at 100 gal/min. The mean deposit in the 3,500-foot swaths was 0.39 lb./acre; in the 5,000-foot swaths it was 0.34 lb./acre. The results of these and other tests show that the system was capable of blanketing approximately 48 square miles of target with 1,000 gal of chemical.[7,8] Further investigations involved small-capacity spray systems on USN high-performance fighter aircraft.

B. CONTROLLED APPLICATION - DEFOLIATION

The nature of the conflict in Vietnam and the spray mission demanded that new employment concepts, techniques, and equipment be developed. Careful control of chemical sprays was required in order to prevent or minimize damage to economic crops not belonging to the VC. In order to satisfy fully this requirement, the following guidelines were evolved: (i) the missions will be accomplished under inversion or neutral temperature conditions with calm (0 to 5 mph) winds; (ii) the spray will be delivered at 150 feet altitude or lower; (iii) the spray flight will be inwind if direction of flow can be determined; (iv) the MMD of the spray will be coarse (300 μ), an attempt to reduce the number of small droplets available to drift off-target; and (v) delivery aircraft speed will be slow (130 knots) to minimize droplet breakup from impingement of the airstream on the spray at the nozzle and to maintain a capability to stay on target with changes in direction. An objective of the early tests was to obtain ground deposits of 1 gal (approximately 10 lb.) chemical per acre. The first C-123/MC-1 spray configuration satisfied the spray requirements initially; however, the OSD/ARPA evaluation team determined that deposits of 3 gal (30 lb.) of agent per acre were required to insure significant defoliation of upland forest vegetation. Numerous modifications and extensive evaluations were accomplished in efforts to achieve the 3 gal/acre deposits. Ultimately, the A/A45Y-1 spray system was developed and supplanted the earlier models. However, it was not calibrated and performance characteristics were not evaluated prior to 1968 at which time the system was included in studies directed by the Chief of Staff of the Air Force. Concurrent with the calibration studies on the UC-123B and A/A45Y-1 spray system, it was being modified. Two gasoline-burning jet engines were added to the aircraft that now is designated the UC-123K, and wing booms 22 feet long have replaced the 17-foot booms that had been shortened previously by the field units. Performance of the UC-123K and A/A45Y-1 system also was evaluated by APGC, Eglin AFB, Florida, in the 1968 test and evaluation program. The system in operation is portrayed in Figure 7.

FIGURE 7. Defoliation with the UC-123K and A/A45Y-1 System in RVN, 1969.

IX. REVIEW

A. EVALUATIONS

It is of interest to note that, among all the controversial subjects that are parts of the conflict in Vietnam, the use of vegetation-control agents, "defoliation," continues to receive an undue amount of publicity that is generally critical. Protest groups have objected to the use of defoliants but appear to be most concerned with the war itself, that people are being killed with the unique methods that tend to incite strong emotions, such as the use of napalm. A much smaller group, predominantly scientists, has chosen to criticize the use of herbicides on "scientific," economic, and/or political bases since the defoliants do not kill or maim as conventional weapons. The U.S. Government has not been insensitive to their pronouncements and justification for continuation of the RANCH HAND program has been reviewed periodically, with the last evaluation (among others) completed late in 1968. The conclusions of each evaluation recognize that defoliation has reduced the incidence of ambushes, has saved lives, and has disrupted VC/NVA tactics; the crop-denial efforts have made subsistence of the enemy in the field more difficult and have adversely affected his operations. Each evaluation group, in turn, approved or recommended continued use of the vegetation-control system.

B. SCOPE OF OPERATIONS IN VIETNAM

The number of acres sprayed yearly from 1962 through 1968 for defoliation and crop destruction are given in the following tabulation based on data furnished in MACV reports:

Year	Acres Sprayed		
	Defoliation	Crop Destruction	Total
1962	4,940	741	5,681
1963	24,700	247	24,947
1964	83,468	10,374	93,842
1965	155,610	65,949	221,559
1966	741,247	101,517	842,764
1967	1,486,446	221,312	1,707,758
1968	1,267,110	63,726	1,330,836

This information serves to indicate the magnitude of the overall effort and the increasing intensity of spray operations with time. Further, since most requests for spray operations are submitted by field commanders, the information is indicative of their recognition of the importance of the program to the fighting troops.

X. APPRAISAL

A. VIETNAM

The introduction of a vegetation-control capability into the armed conflict in Vietnam is unique in modern warfare, in that the method does not kill, maim, or otherwise harm people nor destroy their buildings. In fulfillment of a defensive role, defoliation in critical areas has taken the initiative from the enemy for a favorite tactic, e.g. launching a close-in, demoralizing, surprise attack, then withdrawing before a counterattack can be launched by the defenders. When the screening foliage required for successfully mounting such an operation is reduced or eliminated, the enemy is faced with the prospect of exposure. Defoliation of enemy lines of communication (roads, trails, waterways, etc.), staging areas, and camps has exposed enemy activities and revealed otherwise unseen targets. The enemy abandons treated areas.

Offensive strikes against food crops have denied the enemy large quantities of food. VC/NVA defectors report food shortages, hunger, discontent, and the requirement for more and more foraging parties to obtain food supplies. No question has been raised on the effectiveness of available systems to destroy crop productivity. However, there have been serious questions regarding the sociological and political impacts of antifood operations. Efforts have been made to weigh the effects of crop destruction on the enemy against the attitudes of the Vietnamese, whose produce is taken by the VC/NVA troops, and the influence of public opinion at home and abroad is considered. No conclusive study has been accomplished, and while the subject is still open for debate, anticrop operations have continued in Vietnam where many commanders are convinced of the military worth of the effort.

B. SYSTEM LIMITATIONS

It has been shown that the vegetation-control systems in Vietnam are capable of producing militarily significant effects and that these systems have earned a permanent place in military operations. It is recognized, however, that the systems currently in use have limitations that may be eliminated only by improvement of performance of the various components.

1. Delivery Aircraft

The UC-123 aircraft currently in use has developed a remarkable record of reliability in Vietnam. During the period starting with the last 3 months in 1965 through the first 8 months of 1968 the UC-123's flew almost 11,000 sorties and received nearly 2,000 hits from ground fire, and only four of the aircraft were lost to enemy fire. In the Vietnam conflict, the only opposition has been from ground fire, whereas in a high-intensity war, fighter aircraft and more sophisticated antiaircraft missiles could be expected to effectively counter slow, cargo-type aircraft such as the UC-123. More versatile delivery systems and support technologies must necessarily be developed to provide for unrestricted employment of vegetation-control agents.

2. Vegetation-Control Agents

The agent components of the current systems, on crop-control missions, have produced results as predicted because they were developed initially for that purpose. In the defoliation role, the agents have satisfied the objectives visualized at the time of their introduction into Vietnam. PURPLE and ORANGE disrupt the normal physiologic processes of the sensitive plant system and defoliation results even though the affected plant may recover partially or completely. An extensive array of broad-leaved plants is killed by dosages adequate to cause defoliation. Intensive use of these compounds in Vietnam demonstrates that some few species appear to be immune from the effects of the growth-regulator chemicals, thus complete defoliation of mixed forest targets has not been accomplished. Another limitation of these compounds is that maximum defoliation is achieved slowly; peak in effects from use of ORANGE is about 3 months, from use of WHITE, 5 months. A chemical defoliant agent that will produce effects much more rapidly on all treated vegetation is desired. Agent BLUE functions as a contact or desiccant chemical and produces local effects (browning, shriveling, and necrosis). Since translocation of the chemical from the point of contact is not a requirement, the effects develop more rapidly than with ORANGE and WHITE. However, with some plant species regrowth soon follows defoliation (30 to 60 days). Frequent retreatment is required where BLUE is used and long-term effects are desired.

C. RDT&E

Development of chemical vegetation-control agents is the responsibility of the Army and the work is accomplished in the Plant Sciences Laboratories, Fort Detrick, Frederick, Maryland. The work leading to development of improved chemical agents was initiated in 1961 and represents a modest level of effort in the exploratory development category. The general objectives to be satisfied include: (i) develop a nonselective agent capable of causing rapid defoliation without destruction of valuable forest species; (ii) develop a nonselective chemical agent capable of causing defoliation and persistence of effects for 1 year (or more); and (iii) develop a nonselective agent capable of causing rapid defoliation with effects persisting for at least 6 to 9 months.

Work on delivery systems is the responsibility of the individual services to fulfill assigned missions.

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13. ABSTRACT

Information is provided on chemical vegetation-control systems employed in Vietnam for defoliation, destruction of screening vegetation, and denial of agricultural products (mainly food) to the enemy. Pertinent technical data on research, development, and tests of agents and dissemination systems currently in use are emphasized. The large volume of documentary material has been screened and summary information selected or prepared with a view toward the possible utilization of the data by personnel involved in support and employment of the weapon systems.

14. Key Words

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