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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

DEPARTMENT OF THE ARMY
Fort Detrick
Frederick, Maryland

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INFORMATION MANUAL FOR VEGETATION CONTROL IN SOUTHEAST ASIA

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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 Published material was complemented by unpublished records of tests, observations of research and operations personnel, and informal correspondence, memoranda for record, and notes.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.

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

2. Dissemination Studies

The earliest military, aerial spray trials were accomplished in 1944 and 1945 using the Chemical Corps M-10 smoke tank hung externally on a B-25 aircraft and two different bomb bay spray devices. Three different 2,4-D mixtures were used in the tests.[3,4] By 1951 it had been determined that the vegetation-control agents of choice would be: n-butyl 2,4-D, n-butyl 2,4,5-T, and mixtures of the two. While major emphasis was on the delivery of these chemicals to crop targets, their use for defoliation and target marking also was considered. Because of the conflict in Korea and the possible need for vegetation-control systems there, RDT&E on delivery technologies was intensified with active participation by the Air Force and Navy. Testing programs that followed were addressed to the development of capabilities for attacking extensive targets effectively and efficiently. The objectives were for dissemination of undiluted chemical agents as elevated line sources, normal to wind direction, with the mass median diameter of the spray below 175 μ and deposits on target of 0.1 lb./acre or greater. The low rates are effective on sensitive, annual plants and the fine droplets provide for efficient utilization of the payload (broad swath width and large numbers of droplets per unit area).

Early in 1951, dissemination studies were initiated with experimental spray devices; both USAF and USN equipment was used. Subsequently, three additional series of studies were accomplished, with tri-service participation.[5-7] The last phase of testing in 1952 included studies on the prototype spray device that, when engineering was completed, became the time-honored Hourglass or MC-1. The latter study was a jointly sponsored USAF/USA test and was the culmination of effort on prop-driven aircraft.[7] During 1953, the USAF accomplished prove-out and acceptance testing of the large-capacity spray system[8] and developed an operational capability for its employment, although it was never used.

3. Defoliation - Camp Drum, 1959

At the close of the Korean conflict (1953) the stockpile of vegetation-control agents was disposed of. Crops Division obtained 200 drums of the material and placed it in open storage at Fort Detrick. After 4 years in storage the entire stock was given to the U.S.D.A., Beltsville, Maryland. Approximately 2 months later the Commanding General, 1st U.S. Army, requested that Fort Detrick assist them in their efforts to clear vegetation from an artillery impact area at Fort Drum, New York. Thirteen drums of the chemicals were retrieved from the U.S.D.A., a helicopter spray device developed by Crops Division was brought out of storage and mounted in an H-21 helicopter, and the vegetation on 4 square miles of impact area was sprayed with the system.* The Camp Drum project in 1959 represents the first large-scale, military defoliation effort.

* J.W. Brown, Vegetation Control, Camp Drum, 1959.

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.

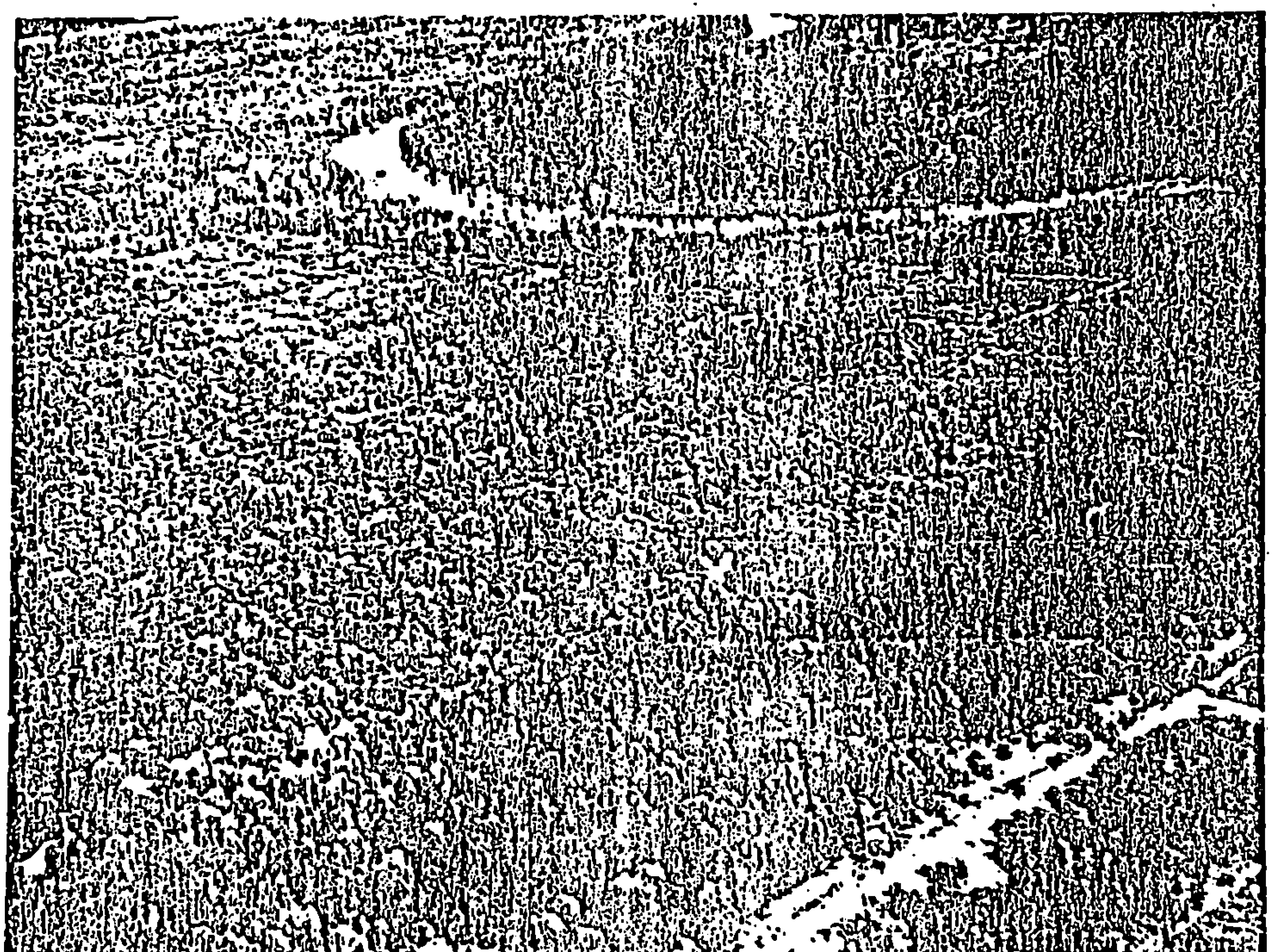

FIGURE 1. Defoliation in Mangrove Vegetation Along Waterway in RVN.

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.[a] 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.

* 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.

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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-51146, Herbicide; n-butyl 2,4,5-trichlorophenoxyacetate
MIL H-60724, Herbicide; isooctyl 2,4,5-trichlorophenoxyacetate

Physical, Chemical, and Biological Properties

a. Physical State

ORANGE and ORANGE II are liquids at room temperature and above, ing from clear reddish brown to straw color. Both agents become more ous at lower temperatures and may solidify at 40 to 45 F. n-Butyl r of 2,4,5-T freezes below 70 to 75 F, but both n-butyl ester of 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 her 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 re characterized by plant physiologists as volatile herbicides because he 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 nature 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.

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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

* 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.

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ORANGE and ORANGE II act principally on broad-leaved woody and herbaceous plants. Grasses, including bamboos, are relatively unaffected by normal rates of application (3 gal/acre) but chemical "burning" and topkill may result from heavier doses of ORANGE and ORANGE II.

6. Effectiveness as an Anticrop-Agent

ORANGE and its component esters of 2,4-D and 2,4,5-T are effective herbicides against many broad-leaved crops. The selective action of 2,4-D on broad-leaved weeds, in contrast to the resistance of cereal and grass crops, has led to its widespread use as a selective herbicide in broad-leaved weed control. The component 2,4,5-T ester is more effective on woody plants and is proportionately more effective than 2,4-D in herbicidal action on crops such as potatoes, soybeans, peanuts, tobacco, sweet potatoes, and rubber trees.

In general, ORANGE may be considered as an effective anticrop agent against most broad-leaved crops at the rate of 1 lb. acid equivalent per acre. Specific rates for crops are given in Section IV,B,1. Highly sensitive crops include:

Cotton	Green beans	Rutabaga
Soybeans	Peas	Poppies
Tomatoes	Sunflower	Beets
Sweet potatoes	Kale	Cabbage
Peanuts	Broccoli	Hemp
Lima beans	Sesame	

Root or tuber crops such as potatoes, sugar beets, and manioc show greatest yield reductions from chemicals applied during early growth stages. Because of the sensitivity of crop plants, spray devices used to disseminate ORANGE should not be used for the employment of insecticides because trace quantities of the herbicide can damage crops.

B. BLUE

BLUE is the code designation for a neutralized, liquid formulation containing cacodylic acid (dimethylarsinic acid) and its sodium salt. The term BLUE was first applied in 1961 to 1964 to cacodylic acid in powder form, containing 65% active ingredient that was mixed in the field with water. The BLUE currently in use is a liquid formulation produced by Ansul Company and is designated Phytar 560G. It contains a minimum of 21% sodium cacodylate with additional free cacodylic acid for a total dimethylarsinic acid equivalent of not less than 26% or 3.1 lb./gal. Phytar 560G contains 5% by volume of a surfactant plus 0.5% of an antifoam agent. Efforts are being made to reduce the surfactant to 1% by volume. Approximate cost is $3.35/gal.

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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 affect 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.

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

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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.

* 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 non-corrosive, 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.

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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 f— industrial use in high-volume sprays. Aerial spray applications of th 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 30% 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.

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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

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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.