

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 monocotyledonous 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

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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.

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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:

	<u>0.1 lb./acre</u>	<u>1.0 lb./acre</u>
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:

	<u>0.1 lb./acre</u>	<u>1.0 lb./acre</u>
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: western hemlock, Norway spruce, Chinese elm, black locust, red maple, pin oak, California privet,

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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:

	<u>ORANGE</u>			<u>WHITE</u>			<u>BLUE</u>		
	<u>1</u>	<u>5</u>	<u>10</u>	<u>1</u>	<u>5</u>	<u>10</u>	<u>1</u>	<u>5</u>	<u>10</u>
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 defoliant 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:

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	<u>Rate, lb./acre</u>		<u>Rate, lb./acre</u>
<u>Rice</u>		<u>Potatoes</u>	
Tandex	0.5	Picloram ester	0.5
Bromacil	0.5 to 1	WHITE	1
BLUE	0.5 to 1	ORANGE	4 to 8
Diuron	2 to 4		
		<u>Soybeans</u>	
<u>Wheat (winter)</u>		Picloram ester	0.25
WHITE	2 to 4	WHITE	0.25
Picloram ester	2 to 4	ORANGE	0.5 to 1
Bromacil	2 to 4	Tandex	1 to 2
Tandex	2 to 4	Bromacil	1 to 2
BLUE	2 to 4		
		<u>Castorbeans</u>	
<u>Sugarcane</u>		Picloram ester	0.5
Bromacil	5 to 15	ORANGE	0.5
Tandex	5 to 15	WHITE	1
<u>Corn</u>		<u>Manioc</u>	
BLUE	1 to 2	WHITE	0.2
Dalapon	2 to 4	Picloram ester	0.5
Bromacil	4	ORANGE	1
Tandex	4 to 6		
Diuron	4 to 8		

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 HIDA, 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

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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.

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TABLE 1. DEFOLIATION RESPONSES FROM ORANGE
IN TROPICAL FOREST SITES^a

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	<u>April 1966 Application</u>				
1.5	61	65	52	- ^a /	38
3.0	73	79	66	-	55
6.0	75	91	71	-	61
3.0	46	62	75	-	-
Hilo, Hawaii:					
ohia, tree fern forest	<u>December 1966 Application</u>				
3	45	60	62	58	55
Kauai, Hawaii:					
ohia, guava, java plum	<u>December 1967 Application</u>				
3	71	84	80	-	-
Thailand:					
dry evergreen forest	<u>May 1964 Application</u>				
3	-	90	66	50	30
3	40	57	60	45	32
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		Dry Season Application	
	Canopy		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 APPLICATION²³

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.

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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).

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TABLE 5. DURATION OF DEFOLIATION OF TROPICAL VEGETATION
WITH AERIALY APPLIED BLUE¹

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.

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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.

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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 $\frac{1}{2}$ -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.

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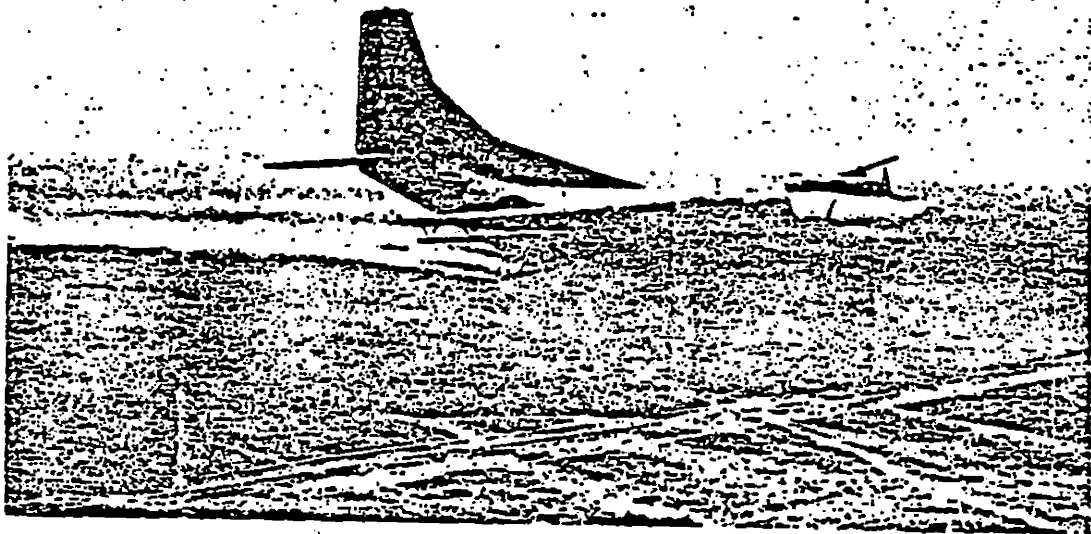


FIGURE 2. UC-123B Aircraft with MC-1 Spray System as Modified in the 1963 Eglin AFB Calibration Trials.

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

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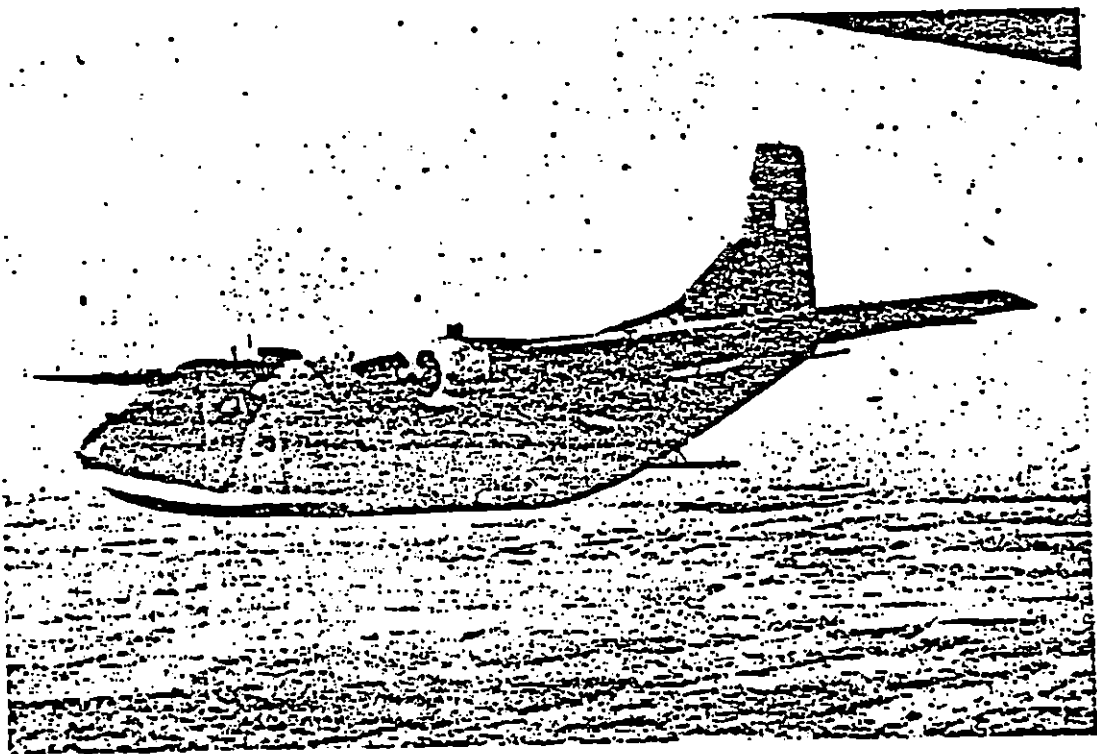


FIGURE 7. UC-123K Aircraft with A/A45Y-1 Internal Defoliant Dispenser
Used for Defoliation in RVN in 1968 to 1969.

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.²⁸ 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.

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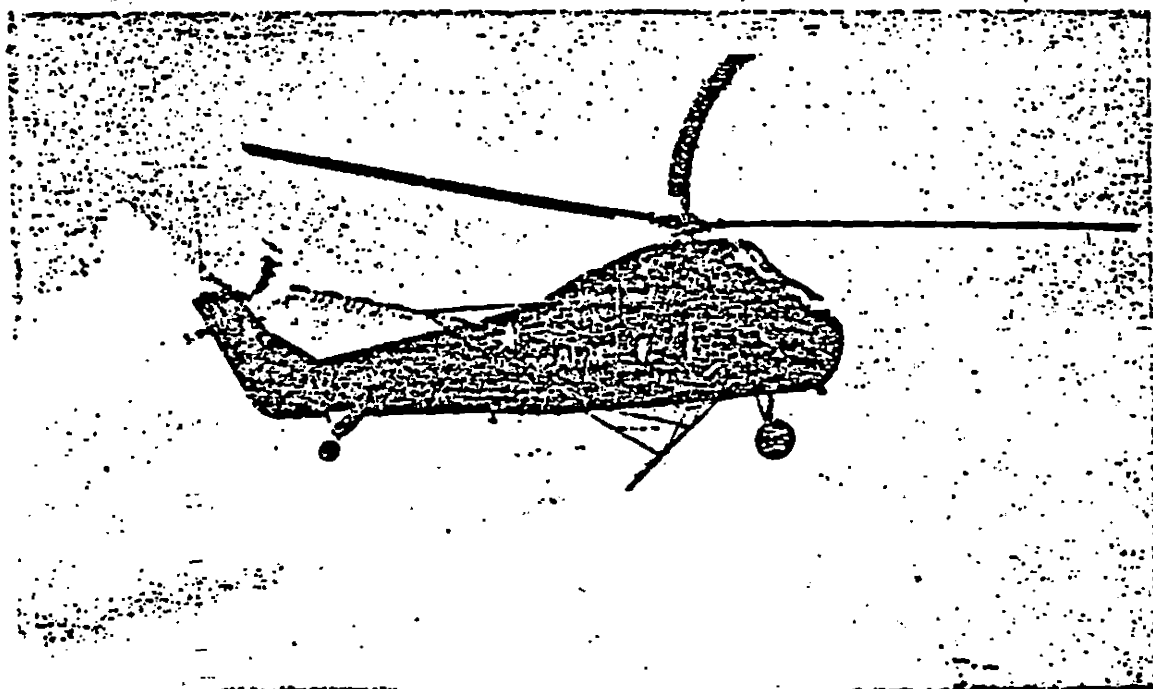
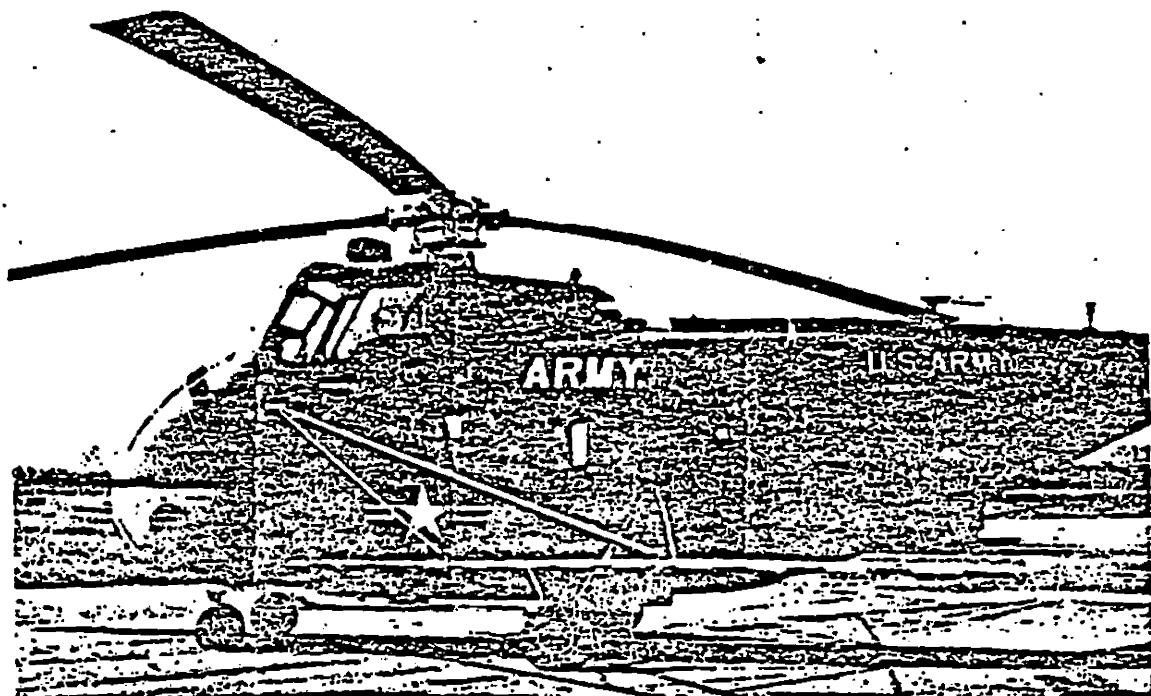


FIGURE 4. HIDAL Unit Used with H-19 (Upper) and H-34 (Lower) US Army Helicopters.

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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.

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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 ft³/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 ft³ 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-ft³/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.

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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.

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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.

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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.

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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.

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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 ($\leq 100 \mu$), 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.³

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

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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 ARGC, Eglin AFB, Florida, in the 1968 test and evaluation program. The system in operation is portrayed in Figure 7.

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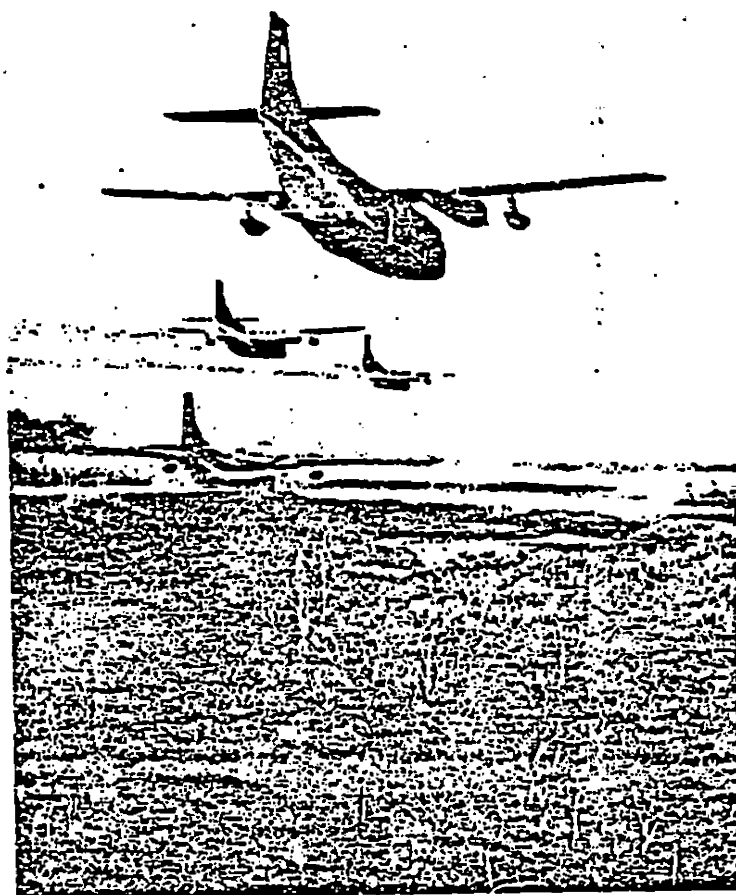


FIGURE 7. Defoliation with the UC-123K and A/A45T-1 System
in RVN, 1969.

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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.

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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 antifeed 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

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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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