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Weed Control Practices and Research for Sugar Cane in Hawaii[1]

Noel S. Hanson[2]

Abstract and Summary. Chemical control of weeds in the Hawaiian sugar industry began in 1913 when experiments with sodium arsenite were first conducted on the Island of Hawaii. Sodium arsenite and some sodium chlorate were the main herbicides in use until a concentrated, activated diesel emulsion (CADE) was developed in 1944. From that time on the chlorophenoxyacetic acids and their compounds, sodium trichloroacetate, sodium 2,2-dichloropropionate, and the substituted ureas and triazines have, in turn, been incorporated into use on plantations for weed control. At present, over a half million acres are sprayed each year at a cost of nearly seven million dollars for labor and material.

Introduction

Sugar cane is grown in Hawaii on approximately 220,000 acres of land, from near sea level to above 3,000 feet elevation, and under rainfall from less than 15 inches plus irrigation to over 250 inches annually. Approximately one-half of this acreage, which comprises 27 plantations and more than 1,200 independent growers, is harvested each year and a new crop is started, either by planting anew or by ratooning the fields. At present, nearly all weeds in sugar cane in Hawaii are controlled by herbicides. Each field is sprayed on an average of five times before the sugar cane is large enough to "close in" over the interrow spaces. Consequently, more than a half million acres are sprayed for controlling weeds each year at an annual cost of nearly seven million dollars for material and labor.

Fundamental research on weed control in sugar cane is, for the most part, conducted in the laboratories at the Experiment Station in Honolulu. Applied research is carried out in field tests on a cooperative basis, either on the plantations on the Islands of Hawaii, Kauai, Maui or Oahu, or at the Waipio Substation on Oahu. This cooperative testing is conducted by personnel of the plantations' Agricultural and Weed Control Departments and the research workers of the Experiment Station, including the staffs of Station Island Representatives on three islands. Research on new herbicides is also cooperative with the manufacturers and their local distributors.

Historical

Chemical control of weeds began in the Hawaiian sugar industry in 1913 when experiments with sodium arsenite were installed at Olaa Sugar Company (now Puna Sugar Company) on the Island of Hawaii (2). From that time until about 1945, sodium arsenite in water was the main herbicide used in sugar cane. During the 1930's, sodium chlorate reached limited use but, because of its fire hazard, did not find wide acceptance (3, 4). During 1944, Dr. F. E. Hance and Mr. F. C. Denison of the Experiment Station staff started a series of tests leading to the development of a contact-herbicide formula, including sodium pentachlorophenate (sodium PCP) and diesel oil, to be known as concentrated, activated, diesel emulsion (CADE) (5). The CADE formula was reworked by Drs. F. E. Hance and H. W. Hilton to include aromatic oils (ARCADE) in 1953 and with pentachlorophenol, (PCP) to formulate ARCADE concentrate (ARCON) in 1958 and another HSPA formulation with PCP (Pentacide) in 1961.[3]

The acid, salts and esters of 2,4-dichlorophenoxyacetic

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acid (2,4-D) came into wide scale use on plantations as systemic, postemergence herbicides in 1945 and for preemergence control of a broad spectrum of monocotyledonous and dicotyledonous weed species in 1947. Since that time 2,4-D has been used in its several forms alone and in combination with other herbicides for both preemergence and postemergence control of weeds. Its most common usage has been in combination with CADE, ARCADE, and ARCON, where the emulsion has played the important role as a contact herbicide for emerged weeds with 2,4-D to prevent further emergence through action on young weed seedlings prior to their emergence (6).

Sodium trichloroacetate (TCA) came into general use in 1948 following experiments demonstrating effective control of Bermudagrass, *Cynodon dactylon,* in low rainfall areas, and on torpedograss, *Panicum repens,* tall panicum, *Panicum purpurascens,* and Hilograss, *Paspalum conjugatum,* in high rainfall areas. Severe infestations of these grass species were present on many plantations in 1948. Several plantations were in danger of going out of business because of low sugar cane yields which, in many cases, were due to heavy infestations of the above grasses. Sodium TCA played a major role in bringing these infestations under control so that yields of sugar cane could be increased to economically practical levels (9) (Figure 1). Sodium salt of 2,2-dichloropropionic acid (dalapon) found extensive use as a grass killer beginning in 1953 to supplement sodium TCA on the above-named and other grassy weeds.

The substituted ureas, 3-(*p*-chlorophenyl)-1,1-dimethylurea (monuron) in 1951 and 3-(3,4-dichlorophenyl)1,1-dimethylurea (diuron) in 1953, came into extensive use as preemergence herbicides and are still playing a major role in plantation weed control programs. Since 1960, the *s*-triazine derivatives, 2-chloro-4,6-bis(ethylamino)-*s*-triazine (simazine) and 2-chloro-4-ethylamino-6-isopropylamino-*s*-triazine (atrazine) have also been used on large acreages for preemergence weed control with the latter showing considerable value for postemergence control in recent tests.

Other herbicides, such as 3-amino-1,2,4-triazole (amitrole) and 2,3,6-trichlorobenzoic acid (2,3,6-TBA) have received extensive testing and registration is currently being sought with the U. S. Department of Agriculture for their use in sugar cane. Most herbicides that have become available for testing in recent years have been tried either in the laboratory or field to determine their value in comparison with herbicides already registered and accepted for use in plantation fields.

During the last 14 years, as a result of research on spray equipment, application methods and timing of operations have been improved to the extent that precision, low-gallonage treatments of from 2.5 to 25 gallons per acre are adequate to satisfactorily apply most herbicides for effective weed control.

Figure 1. Before and after control of Bermudagrass (Manienie) in a field at Kilauea Sugar Company on the Island of Kauai. Above—Large areas of this 105-acre field were so heavily infested with Bermudagrass that there was little, if any, sugar cane. At harvest, the yield was only 15.6 tons of cane and 1.7 tons sugar per acre for the field. Below—The same field at 11 months of age following effective control of all weeds. After harvest of the crop above, the field was plowed, rototilled twice, the grass and rootstocks raked and burned. After planting, the field was given two sprays of 2,4-D, followed by three spot sprayings of sodium TCA for grass control, the last with 2,4-D in combination. When the crop shown below was harvested, the sugar cane yield was 69.4 tons and 6.9 tons sugar per acre for the field.

Major Weed Problems

In addition to a large number of non-rhizomatous species of broad-leaved and grassy weeds, there are several rhizomatous or stoloniferous species, mainly grasses, that constitute special problems in and adjacent to sugar cane fields. Some of the major species found in fields are as follows:

Non-rhizomatous species

Grasses (Monocots)

Digitaria pruriens—slender crabgrass
Digitaria sanguinalis—large crabgrass
Digitaria violascens—violet crabgrass
Digitaria pseudo-ischaemum—smooth crabgrass
Eleusine indica—goosegrass
Chloris radiata—plushgrass
Chloris inflata—swollen fingergrass
Echinochloa colonum—jungle-rice
Echinochloa crusgalli—barnyardgrass

Broad-leaved (Dicots)

Amaranthus spinosus—spiny amaranth
Portulaca oleracea—purslane
Crotalaria incana—hairy rattlepod
Crotalaria saltiana—smooth rattlepod
Euphorbia hypericifolia—graceful spurge
Emilia sonchifolia—Flora's paintbrush

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Leucaena glauca—false koa
Ricinus communis—castorbean
Erechtites hieracifolia—fireweed

Rhizomatous, stoloniferous, bulbous, cormous, or tuberous species

Grasses (Monocots)

Cynodon dactylon—Bermudagrass
Panicum purpurascens—tall panicum
Panicum repens—torpedograss
Paspalum conjugatum—Hilograss

Broad-leaved (Dicots)

Impomoea spp.—morningglory
Tritonia crocosmaeflora—Portuguese lily
Commelina diffusa—dayflower

Sedges (Monocots)

Cyperus rotundus—purple nutsedge
Cyperus esculentus—yellow nutsedge
Cyperus brevifolius—green kyllinga
Cyperus kyllinga—white kyllinga
Cyperus polystachyos—fieldsedge

During the period of nearly 50 years in which herbicides have been used in sugar cane on Hawaiian plantations, there have been shifts in major weed populations. After continued use of contact-type herbicides, such as arsenicals and CADE, it was recognized by 1948 that non-rhizomatous, broad-leaved, and some grass species had been replaced by heavy infestations of the rhizomatous and stoloniferous grasses, including those mentioned above. These pernicious grasses had taken over vast areas of sugar cane land. Likewise, the stoloniferous dayflower *Commelina diffusa* had infested large areas.

With the development of the systemic herbicides, 2,4-D for dicots and sodium TCA and sodium dalapon for monocots, the rhizomatous and stoloniferous species were gradually brought under control. In these infestations, however, potentially herbicide-tolerant strains of some species have evolved. Strains of Bermudagrass tolerant to both sodium TCA and sodium dalapon have been isolated by continued chemical selection. One strain from Kilauea Sugar Company on the Island of Kauai, and another strain with somewhat different morphological characteristics from Honokaa Sugar Company on the Island of Hawaii, have shown high tolerance to sodium dalapon as compared with a strain from the Experiment Station in Honolulu. These strains are shown in Figure 2. A strain of dayflower *Commelina diffusa,* resistant to 2,4-D but not to 2,4,5-T, was found at Paauhau Sugar Company on the Island of Hawaii. There appears to have been a definite increase in tolerance to 2,4-D by fireweed *Erechtites hieracifolia* plants in present populations as compared with those in populations sprayed with 2,4-D from 1945 to 1950. It is to be expected that, as spraying of a particular herbicide continues, genetic segregation may in time yield strains of plants with increased tolerance to that herbicide. This could happen with any herbicide used exclusively by itself.

Shown in Figure 3 is a schematic graph based on the reaction of two dicotyledonous weed species in comparison with most other dicots encountered in sugar cane in Hawaii. Most individuals of *Commelina diffusa* are killed by 2,4-D between the levels of 1 and 4 lb/A, but a strain has been found in which the individuals tolerate more than 5 lbs. The amount of 2,4-D needed to kill the more tolerant individuals in this strain is not known but it is well above 5 lb/A. Most other dicots have been killed at levels of 2,4-D between 2 and 8 lb/A with a few less tolerant and a few more tolerant, but not withstanding more than 10 lb/A. In this category are such species as *Richardsonia scabra,* purslane, *Portulaca oleracea,* Flora's paintbrush, *Emilia sonchifolia,* hairy rattlepod *Crotalaria incana,* smooth rattlepod, *Crotalaria saltiana,* and other dicots listed above.

Another species, wing-leaved passionflower, *Passiflora pulchella,* which occurs only in two known locations in

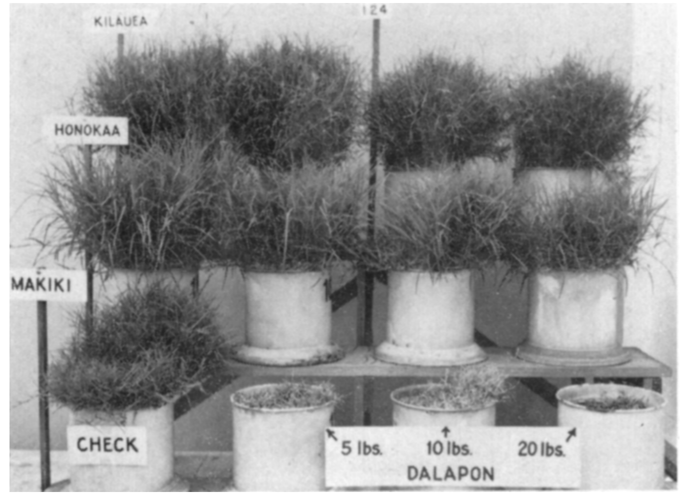

Figure 2. Three strains of Bermudagrass. Those from Kilauea Sugar Company and Honokaa Sugar Company have shown high tolerance to dalapon, as illustrated above. The Makiki strain from the lawn at the Experiment Station, HSPA, in Honolulu, exhibits what is considered to be normal susceptibility to dalapon. The pots, as indicated, have been treated with 0, 5, 10 and 20 pounds sodium dalapon per acre. As many as six applications at these rates did not affect the Kilauea and Honokaa strains. Similar tolerance has been demonstrated with sodium TCA at equivalent dosages. These strains have been destroyed with 25 to 50 pounds monuron per acre and with varying dosages of amitrole alone and in combination with monuron.

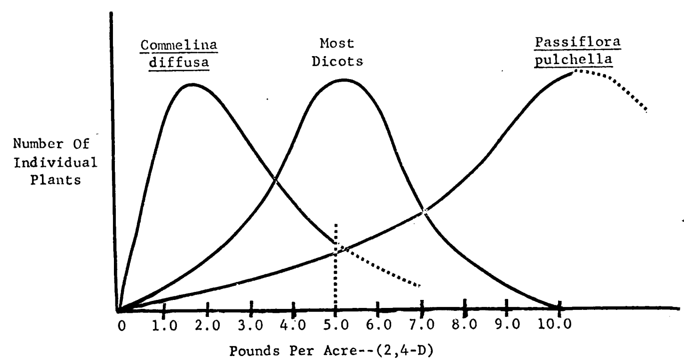

Figure 3. Differential reaction of weed species to 2,4-D. The curves indicate the wide difference in tolerance of two species of dicotyledonous (broad-leaved) weeds in comparison with most other dicots on which observations have been made.

Hawaii, has a tolerance to 2,4-D so high that relatively few individuals are killed at less than 10 lb/A, the majority of individuals tolerate 10 lb or more, and the upper level is unknown at present. In fact, the tolerance of individuals of this species to most herbicides is so high that thus far none of the many herbicides tested have shown value within economically practical limits.

Current Practices

Because of the close association of research results to practices carried out in plantation fields, both are covered.

Herbicides. Of the herbicides mentioned above, 2,4-D, sodium dalapon, sodium TCA, monuron, diuron, simazine, atrazine; the emulsions with PCP, such as ARCON and Pentacide, and straight aromatic oil are the ones in current use. These have been approved by the U. S. Department of Agriculture and have gained wide acceptance by the sugar plantations. Combinations, such as 2,4-D and ARCON; 2,4-D and sodium dalapon; 2,4-D, sodium dalapon, and sodium TCA are in common usage. Both the substituted ureas and the triazines have been applied in combination with PCP emulsions. In such use, the emulsion is a contact herbicide to destroy weeds already emerged and the substituted urea or triazine is applied to the soil to effect control of seedlings not yet emerged. A typical program on any plantation is as follows:

1. First application—diuron or atrazine, 4 lb/A, alone or in combination with ARCON, at 1 in 4 dilution in water, and applied by sprayplane. This application will control non-rhizomatous weeds from 6 to 8 weeks.
2. Second application—repeat with atrazine or simazine, 4 lbs/A in water, by sprayplane over young cane, or apply inter-row by spray-tractor in unirrigated fields. Irrigated fields are furrowed and have irrigation flumes at close intervals. Tractors are not recommended in irrigation fields following flume installation. Inter-row application by spray gang may be done in irrigated fields. Inter-row application may include monuron or diuron for continuing preemergence control.
3. Third application—Spot treatment of emerged weeds with 2,4-D plus sodium dalapon and, perhaps, sodium TCA, where rhizomatous grasses are present. When only non-rhizomatous grasses and broad-leaved weeds are present, 2,4-D and ARCON may be used. This application is made mainly by spray gangs of men carrying knapsacks.
4. Fourth, fifth or subsequent applications—Repeat as needed with materials as in the third treatment until the cane closes in to shade the ground.

The herbicides are mixed at a central plant (Figure 4) and supplied to the application units working in the field.

Application. Herbicides are applied by sprayplane, spraytractors for broadcast or inter-line treatment or by groups of spray men carrying pressure or pump knapsacks. The latter are supplied infield from tanker-truck units which move along field roads. These have hoselines to deliver the herbicides to the men who are working in the fields. Most gangs are supplied with single, double, or triple tank pressure knapsacks which are pressurized with air or compressed nitrogen to 30 pounds per square inch when empty of liquid. When filling a knapsack, the hoseline from the tanker is attached by quick-coupler and the chemical mix is injected into the unit. The liquid is provided under pressure by pump at the tanker forcing the herbicide through the hoseline to fill the knapsack. Most knapsacks are calibrated so that filling to 100 pounds per square inch with liquid against an initial air pressure of 30 pounds per square inch will give a capacity of 5 gallons of spray material.

The sprayplanes are rebuilt Stearman biplanes provided by a commercial operator. They are equipped with fiberglass tanks and conventional nozzles for air spraying. The pump is operated off the engine.

The spraytractors are, for the most part, crawler-type units with conventional spray equipment attached for either broadcast (over-all) or inter-row spraying. (Figure 5).

Figure 4. Herbicide mixing plant at Ewa Plantation Company on the Island of Oahu. This plant supplies concentrates and field mixes for about 25,000 acres of weed control annually. Supply of active ingredients being delivered to the plant at right and tanker taking on field mix at left. Oil storage is below ground except for the small tank supplying the mixing vat, as shown in the center. This plant operation is handled by one man.

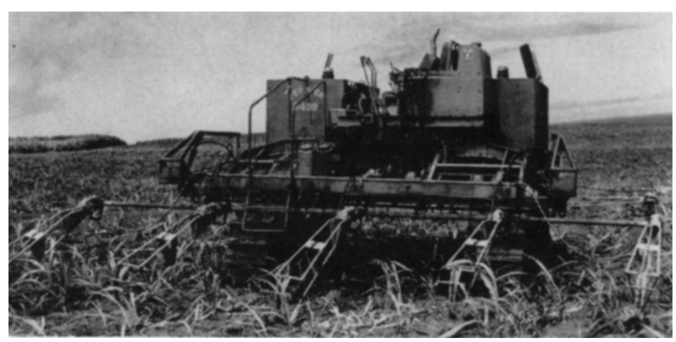

Figure 5. Inter-row spraytractor at Pepeekeo Sugar Company on the Island of Hawaii. This unit is called a "high and wide". It is a specially constructed tractor for use in sugar cane fields with the track spread great enough to straddle two rows 4½ feet apart and for clearance of sugar cane 30 to 36 inches tall. The nozzles are mounted on skids as indicated. Each assembly sprays one inter-row space with overlap at the base of the plants. The unit has five skids at each end and these spray five inter-row spaces per swath each direction. In operation, the tractor angles across rows at field edge but does not turn 180 degrees. The controls and operator's seat are set at 90 degrees to the frame to afford a full view for two-way operation.

Biological control. Woody plants, such as lantana, *Lantana camara,* and a few others, outside sugar cane fields, are controlled by insects which have been imported by the Hawaii Department of Agriculture working in cooperation with the sugar industry and other agricultural agencies. Also, the fish *Tilapia mossambica* is stocked in many irrigation reservoirs and drainage ditches. By nature of their feeding and reproductive habits, emergent and submerged aquatic weeds are destroyed (Figure 6).

Figure 6. Drainage ditch at Kekaha Sugar Company on the Island of Kauai. This ditch has been stocked with the fish *Tilapia mossambica* for about three years. Note absence of any type of vegetation below the water line. It is destroyed through the feeding and breeding processes of the fish. Bermudagrass on the banks is kept under control, but purposely not killed in order to keep a low vegetative cover on the banks. It is sprayed with a sublethal dosage of dalapon at four to six-month intervals.

Current Research

Current research in herbicides and weed control is centered in two departments of the Experiment Station, HSPA, on a cooperative basis. The preliminary screening formulation studies and some fundamental aspects on soil and sugar cane analyses are handled by the Chemistry Department. The various phases of field testing, some fundamental studies, and the development of application equipment are under the Weed Control Research Department in cooperation with Station Island Representatives and plantation personnel.

Field testing of herbicides. Those herbicides which have a potential equal to or better than those in current use on plantations, based on preliminary screening, are given advanced screening in field tests. Such testing is done under many soil and rainfall conditions to determine weed control value and effect on sugar cane. The evaluation procedure is as follows:

1. Observation tests are installed in 1/100 acre plots in randomized blocks, replicated four times. The herbicides are applied as timed, calibrated sprays by pressure knapsacks with multi-nozzle booms (7). These tests are graded at weekly intervals. Gradings are based on abundance of weeds and on degree of control, according to the following:

Weed control index	Condition observed
1	No apparent control.
2	Slight control.
3	Moderate control.
4	Satisfactory control.
5	Complete control.

Gradings may be done to half points, i.e., 4.5 or 3.5. Index 4.0 is the point at which a plot or field is about to go out of control and where respraying should be scheduled. It is considered as the point on the graph dividing satisfactory from unsatisfactory control. The number of days control is assigned according to the graph in Figure 7, which

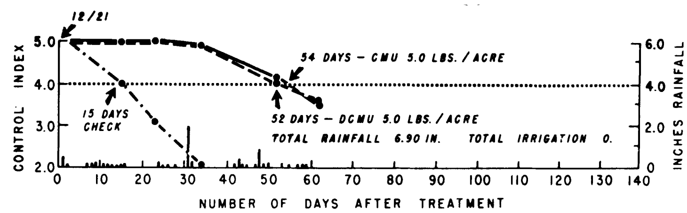

Figure 7. Weed control log.
Experiment No. *49.45* Location: *Kahuku Plantation Company*
Field No.: *20* Sugar cane variety: *37-1933*
Crop: *Ratoon* Moisture: *Irrigated*
Soil: *Alluvial* Equipment: *Pressure knapsack*

Comments: Average of four replications. Predominant weeds were goosegrass (wiregrass) *Eleusine indica,* annual sowthistle *Sonchus oleraceus,* graceful spurge *Euphorbia hypericifolia,* Spanishneedles *Bidens pilosa.*

Legend
—— = (CMU) monuron in ARCADE
– – – = (DCMU) diuron in ARCADE
-.-.- = Check
Ir. = Date irrigated
Bar graphs = Inches rainfall

is based on the average of four replications. This graph is a running record of control. Consequently, it is called the Weed Control Log.[4] Factors, such as rainfall, irrigation, fertilization, or any other practice which may influence the period of weed control, can be noted on this record and serve as a means of evaluation.

Weekly gradings of effect on sugar cane are made at the time of grading for weed control. The following indices are used: (8)

Cane effect index	Symbol	Condition observed
[a]P-5	DP	Double the check.
P-4	HP	Considerably better than check.
P-3	MP	Moderately better than check.
P-2	SP	Slightly better than check.
1	N	No apparent effect.
2	S	Slight effect or chlorosis.
3	M	Moderate effect or chlorosis.
4	H	Heavy effect or chlorosis.
5	D	Plants dead or dying.

[a]P = Plus value

[4]Hanson, Noel S., 1955. Forms of substituted urea as herbicides for controlling weeds on sugar cane lands of Hawaii. Doctorate Thesis, University of Nebraska, pp. 1–86.

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Gradings are made of both adverse and desirable effects. The latter have been observed mainly where the herbicide possesses soil-fumigant properties that may correct or amend deleterious conditions in the soil microflora or microfauna complex. Growth measurements and leaf color may be recorded in some tests. Measurements when made are mainly of stalk elongation. Leaf color indices are recorded in relation to the cane effect indices.

2. Yield data on cane and sugar are obtained in the usual manner. Plots 50 by 40 feet are used as a standard. Sequential yield tests are employed whereby weights of green cane from two rows per plot are recorded at approximately eight months. If no significant difference in growth is recorded at that time, the test is discarded. If significant differences are noted, then the remainder of each plot is harvested at approximately 24 months. Sugar yield, as well as yield of cane tonnage, are recorded at the 24 month harvest at maturity.

Table 1. Varietal reaction to herbicides applied at 5 lb/A in 50 gal/A water over sugar cane plants.

Variety	Herbicide and number of applications[a]							
	Sodium 2,4-D	Amine 2,4-D	Ester 2,4-D	Monuron	Diuron	Simazine	Sodium dalapon	Sodium TCA
	2	2	2	2	2	2	1	1
37–1933	S–M	M	H	M–H	M	N	M–H	S
39–5803	S	S	M	H	H	N	H	N
39–7028	S–M	M	M–H	S	N	N	M	S
44–3098	S–M	S–M	M–H	M–H	S	N	M–H	S–M
49–5	S–M	M	M–H	S–M	N	N	M–H	S–M
49–104	S	S	M–H	M	S–M	N	M	N
49–3533	N	S	M	S	S	N	M–H	N
50–7209	S	S	M–H	N	N	N	M	N

[a]First application over plants when 20–24 inches tall. Second application over plants when 30–36 inches tall.

In Table 1 is shown the reaction of eight varieties of sugar cane to eight different herbicides when applied over the foliage at five pounds active in 50 gallons water per acre. Application was done over the crop at 20 to 24 inches tall and again at 30 to 36 inches, except for sodium dalapon and sodium TCA which were applied only when the plants were 20 to 24 inches tall.

It should be noted that the eight varieties react quite differently to the various herbicides, with sodium dalapon giving the greatest effect and simazine no effect on any variety. Two applications of an ester of 2,4-D were about as damaging as one application of sodium dalapon. Variety 39-5803 was found to be quite sensitive to monuron and diuron. Variety 50-7209 was the most vigorous in growth in the check areas of the eight varieties and was also the least affected by herbicides.

With the system of evaluation outlined above, a large number of tests are conducted each year in plantation fields under many soil and moisture conditions, and at various elevations. These are used as the bases for larger-scale block tests to study costs and practicability of using promising new chemicals in the plantation weed control programs.

The results of two tests to determine effect of herbicides on sugar cane are given in Tables 2 and 3.

Table 2. Effect of dalapon and TCA on sugar cane.
(Lihue No. 459H, Group Test 41-2, FLD. M3c)

Treatment	Herbicide	Lb/A (active)	Diluent	Avg. total green wt.
A	Dalapon (off cane)	5	Water	1008
B	Dalapon (off cane)	5	Water	
	Dalapon (on lower 50% of cane 30–36")	2½	Water	852[a]
C	TCA (off cane)	20	Water	938
D	TCA (off cane)	20	Water	
	TCA (on lower 50% of cane 30–36")	10	Water	928
X	Check	—	——	927
Sequential harvest at 8 months			LSD = 117.7	

[a]Significant reduction in growth only where dalapon was sprayed on lower 50% of plants. Variety 50–7209 May 1961

Table 3. Effect of simazine and atrazine on sugar cane.
(Hakalau, Group Test 41-5, Field 011)

Treatment	Herbicide	Lbs/A active	Harvest at 9.3 months lb green weight		
			Stalks	Tops	Total
A	Simazine (on soil)	4	416	127	543
B	Atrazine (on soil)	4	391	123	514
C	Simazine (on soil)	4			
	Simazine (on cane 15–20")	4	418	126	544
D	Atrazine (on soil)	4			
	Atrazine (on cane 15–20")	4	395	133	528
X	Check	–	370	122	492
	LSD		ns	ns	ns

Simazine soil adsorption 74 & 81%   Variety 49–5   1961

The objective in the Lihue test No. 459H, Group Test 41-2 in field M3c, was to determine the effects of sodium dalapon or sodium TCA on sugar cane variety 50-7209. The effects were noted after the herbicides were applied by directed spray around but not on the foliage of the crop plants as compared with the same treatment followed by one-half the dosage applied on the lower 50 per cent of the sugar cane plants when 30 to 36 inches tall.

The results in Table 2, covering the total green weight at eight months, indicated that a significant difference from the untreated check occurred only where a second application of sodium dalapon was applied to the lower 50 per cent of the plant. There was no deleterious effect on cane from either application of sodium TCA. The remainder of this test will be harvested at maturity, approximately 24 months, to determine whether a significant difference in green weight still persists and, if so, whether it may be expressed in differential sugar yield.

The objective in Hakalau Group Test 41-5 in field 011, as shown in Table 3, was to determine the effect on sugar cane variety 49-5 from spraying four pounds per acre of simazine or atrazine as a single treatment preemergence on the soil as compared with the same treatments followed by a second and similar dosage applied over the sugar cane foliage when the plants were 15 to 20 inches tall. It should be noted that soil adsorption of simazine in the area of the test was found to range from 74 to 81 per cent which has been found by Hilton[5] to be relatively high for sugar cane soils. Soil adsorption of atrazine was not measured but is believed to be high also.

[5]Hilton, H. W., 1961. Unpublished data. Experiment Station, HSPA.

The results, as shown in the same table, show no significance in differences between treatments for either stalk, top or total green weight. This test was terminated and will not be harvested at maturity.

Adsorption of Herbicides to Soil

Studies by Burr and Ashton in 1948 (1) indicated that there was great variability in the retention by adsorption of 2,4-D to soils from sugar cane growing areas in Hawaii. Studies by Sherburne and Freed (10) in 1954 pointed out the importance of herbicide adsorption on soil. Recent studies by Yuen and Hilton[6] (12), and Hilton[7] have shown that monuron, diuron, simazine and PCP are adsorbed at varying levels in sugar cane soils.

The percentage of adsorption of herbicides in Hawaiian sugar cane soils has been found to be greater in surface than in subsoils. Damage to sugar cane from both monuron and diuron has occurred where levels of 4 lb/A or more active herbicide have been applied to soil areas where adsorption level is low. In areas where adsorption percentage is high in the surface soils, there has also been some damage to sugar cane from monuron and diuron in eroded areas where subsoil has been exposed. Less damage has been observed from diuron than from monuron. Differential varietal tolerance to the two herbicides (Table 1) shows that diuron has the least effect on most varieties.

Table 4. Effect of monuron and diuron on sugar cane, varieties 37-1933 and 49-5 in two different plantation soils. Average of two replications.

Herbicide	Herbicide in soil	Herbicide adsorbed	Effect on plants at 11 weeks of age: Cane variety	Herbicide in tissue	Live shoots	Cane top weight	Root volume
	ppm	per cent		ppm	no.	gm	ml
Low humic latosol (Kahuku field 9), pH = 6.8, organic matter 2.75%							
monuron	10	27	37–1933	101	1	45	5
monuron	0	—	37–1933	0	16	515	155
monuron	10	27	49–5	28	4	710	190
monuron	0	—	49–5	0	17	1140	360
diuron	10	26	37–1933	30	4	225	40
diuron	0	—	37–1933	0	13	735	205
diuron	10	26	49–5	19	7	650	130
diuron	0	—	49–5	0	18	1210	450
Alluvial soil (Oahu Sugar Co. field 26), pH 6.0, organic matter 3.5%							
monuron	10	75	37–1933	13	10	700	120
monuron	0	—	37–1933	0	17	1005	240
monuron	10	75	49–5	6	12	1300	330
monuron	0	—	49–5	0	20	1380	350
diuron	10	87	37–1933	12	11	725	80
diuron	0	—	37–1933	0	13	545	65
diuron	10	87	49–5	5	19	1208	240
diuron	0	—	49–5	0	17	1370	250

Table 4 shows the effect of monuron and diuron on two varieties of sugar cane in two different plantation soils. The greater effect on both varieties occurred in the low humic latosol with an adsorption level of 27 per cent for monuron and 26 per cent for diuron. The lesser effect was in the alluvial soil with adsorption of 75 per cent for monuron and 87 per cent for diuron. Variety 37-1933 was affected to a greater degree by both herbicides than was variety 49-5. Organic matter level was only slightly greater in the alluvial than in the low humic latosol soil. Both soils were acid in reaction. The level of each herbicide in the tissues of damaged plants was high, the highest figure being for monuron in tissues of variety 37-1933.

[6] Yuen, Q. H. and Hilton, H. W., 1961. Studies on soil adsorption of preemergence herbicides. January Monthly Report, Experiment Station, HSPA.

[7] Hilton, H. W., 1961. Adsorption of pentachlorophenol on soils. April-June Quarterly Report, Experiment Station, HSPA.

Application equipment.

Knapsacks. The main research in development of application equipment has centered around man-carried, pressure knapsack sprayers to be filled in the field where the men are working, and nozzle arrangements for the most uniform distribution of herbicides. The operation of these units has been discussed. Only the development is covered below.

Pressure knapsacks, with the proper components, have been assembled from surplus oxygen tanks. Some have been fully fabricated from stainless steel. Currently, tanks of glass fiber and polyester resin are being tested. All are required to pass rigid pressure tests for safety.

Figure 8. Double-tank pressure knapsack. This double-tank unit is constructed of stainless steel. It incorporates a tank valve, pop-off relief value and pressure gauge at the top. A quick-coupler injector and pressure regulator are installed at the bottom. The spray is dispersed through the regulator to the hose and gun. Nozzle pressure is 30 psi. Initial air pressure is 30 psi. When liquid is pumped in until the pressure reaches 100 psi, the liquid capacity is five gallons.

Shown in Figure 8 is a double-tank pressure knapsack built from stainless steel. Many such units are currently in use on sugar plantations. Single- and triple-tank units have also been constructed and are in use.

A three-nozzle head, which incorporates off-center, fan-type nozzle tips on the outside and a flat fan tip in the center, may be incorporated with the knapsack. With this arrangement a five-foot, inter-row swath can be sprayed with relatively accurate calibration in gallons per acre.

Spray drift. Herbicidal sprays, particularly with 2,4-D, can be damaging to other crops adjacent to the fields being sprayed for weed control. Studies on spray drift have been conducted in the field and also in a wind tunnel. Low pressure sprays, incorporating the two-orifice system of Yates (11), have been tested in the wind tunnel. This has resulted in a system of low pressure spraying that can be employed in areas where there is a hazard to adjoining vegetation. It consists of using a preorifice .046 inch in diameter at the control valve in the sprayman's hand and a K-10 flooding nozzle with .110 inch orifice for distributing the spray. The barrel of the spray gun acts as a pressure-reduction chamber by which pressure is reduced from 30 psi at the preorifice to approximately 1 lb at the flooding orifice. The spray fan is set parallel to the man's line of travel and is swept forth and back across the inter-line to apply the spray. This results in a pattern of coarse droplets with no mist.

Application in irrigation water. Studies have been conducted with several herbicides, including 2,4-D, 2,4,5-T, silvex, ammonium sulfamate, PCP and sodium PCP, applied in irrigation water. In all cases except with PCP and its sodium salt, the damage to sugar cane has been intense due to great variability in water distribution with consequent over-application of herbicides in some areas.

PCP and sodium PCP have been found to be adsorbed to soil particles near the surface where applied. Consequently, even extremely high levels of PCP have not caused damage to sugar cane. Dosages as high as 2,000 lb/A have not reduced germination or plant growth in the soils where tested. In the same areas, levels as low as 25 to 50 lb/A have given satisfactory weed control. As a result, one plantation has used the method of applying the ARCON formula, which contains one-half pound PCP per gallon in aromatic oil and water emulsion, over several thousand acres of sugar cane fields in irrigation water with satisfactory control. It is being tested on large scale on other plantations.

It has been found that some soils adsorb so high a percentage of PCP that it becomes unavailable for preemergence weed control. The sodium PCP has proven satisfactory for application in irrigation water as well, but may cause more damage to sugar cane because of the higher solubility in water.

Incorporation in surface soil. Several studies with soil incorporation of various herbicides have been conducted. The period of control is not increased sufficiently in the soils, where tested, to warrant wide-scale use. The period of control has been about equal to spray application at the surface. Incorporation has included subsurface spraying, as well as rototilling following spraying at the surface. The tests have shown that the soil surface can be disturbed following treatment without loss of effective weed control.

Future Outlook

There have been nearly 50 years of use of herbicides for weed control on some plantations comprising the Hawaiian sugar industry. During the last 16 years, in 14 years of which observations have been made by the writer, there has been effective and near complete herbicidal control of weeds on most of the plantations. Based on this experience, the following statements appear logical and should be considered for the future. These apply to conditions in Hawaii under which the observations have been made.

1. With the use of contact sprays to supplement mechanical weed control methods from 1913 to 1945, the predominating weed populations shifted from mixtures of dicots and monocots to near complete stands of rhizomatous and stoloniferous grasses in many areas.

2. From 1945 to the middle 1950's, 2,4-D for preemergence control and sodium TCA for preemergence and postemergence control of grasses, along with sodium PCP and oil emulsions as contact sprays, were the main herbicides used. Sodium dalapon also came into use for postemergence control of grasses. During this period, several strains of weeds that are tolerant to these herbicides have been chemically selected. These have needed to be subjected to other herbicides in order to bring about control. As a result, it is believed that the genetic makeup of a weed or crop plant, to a large extent, influences its tolerance or susceptibility to a herbicide. It has been found and demonstrated, through research as well as infield practices, that diversification of herbicides alone, or in combination with other herbicides, or with chemicals which enhance herbicidal action, is needed to bring about control of a broad spectrum of species and individuals within a species.

3. In line with the above, it is believed that the objective should be complete destruction of an existing weed flora in areas treated, within economic practicability. Otherwise, if the more tolerant plants are allowed to grow and seed, there will be a process of herbicidal selection which may result in the development of new populations with high tolerance for the herbicides in use. Diversification of herbicides and modes of action are highly emphasized.

4. The factor, or factors, of physical adsorption of herbicides to soil particles vary greatly from one soil to another, but influence considerably the value of each herbicide for preemergence and some postemergence control of weeds.

5. Although they are not included in this paper, data are at hand and it has been observed frequently in field tests that the physical and physiological well-being of sugar cane, with regard to nutrition and in some cases moisture, plays a large part in the ability of the crop plant to withstand the effects of a herbicide. This appears also to be true of weeds.

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Weeds and Man in Latin America[1]

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WHEN one talks about Latin America, one is talking about approximately 200 million people of a variable kind disproportionately divided among 20 republics comprising an area about 2.6 times the size of Continental United States, not including Alaska.

Differences with respect to topography, climate, ethnic composition, and socio-economic problems are vast and vary greatly, not only among countries, but often within countries as well. In some respects, as one of my Mexican colleagues recently pointed out—"about the only general statement that can be made about Latin America, is that you can't make a general statement about Latin America".

Nevertheless, although many remarks made are subject to certain exceptions or qualifications, the various countries do have many common problems and characteristics. One of the most disturbing things is the deep-rooted restlessness and discontent often exhibited in violent manners on the part of the masses. There is a genuine desire for change—a struggle for a better life which many of the underprivileged are beginning to see possible, but unfortunately they do not fully realize what there is involved in bringing it about.

SOME OF THE SOCIO-ECONOMIC PROBLEMS

People are hungry.

Much of the discontent in Latin America stems from the fact that over 50% of the approximately 200 million people are hungry or undernourished in one form or another. There is not enough food of the quality needed to adequately nourish the present population in many of the countries, or as is often the case with the poverty stricken, their low per capita income (100–300 dollars per year) will just not permit the acquisition of adequate food supplies, even when available. These people often are forced to live in the most primitive kinds of dwellings, crowded together in a most unsanitary way and can afford little more than the barest essentials in the form of clothing and household utensils. In addition to being undernourished, their energies are further depleted because of numerous kinds of parasites and diseases. Modern medical facilities are almost completely unavailable to them. They continue to exist as nature allows them to live, deriving what comfort they may from their superstitions and faith in the hereafter.

Why are people hungry and/or discontented?

Population and food production concentrated in the mountains. In tropical Latin America most of the people live in the highlands because living there is:

1) more pleasant and healthful, and
2) cultivation of food crops is considerably easier—especially maize which is the number one food crop throughout tropical Latin America.

And because they live in the highlands, most of the food production is relegated to the rough terrain of the hills and mountains. In such areas good land is scarce.

The amount of arable land now being used for the direct production of basic food crops is about 0.52 hectares, or 1.28 acres per capita on the average (1). (Range from 0.17 hectares, less than half an acre, in Peru to 1.48 hectares, 3.7 acres, per capita in Argentina. See Table 1.)

Table 1. Number of hectares[a] of arable land per capita in the different Latin American countries.

Country	Population		No. hectares per capita on land use basis			
	Total (thous.)	% Urban	Arable & tree crops	Permanent pasture	Forest	Potential
U.S.A. (Continental)	174,054	64	1.08	1.48	1.49	.035
Latin America (Total)	196,600	—	.52	1.88	4.98	?
Mexico	32,348	43	.62	2.08	1.20	.24
Central America	11,300	33	.41	0.46	2.00	?
Venezuela	6,320	54	.46	2.80	3.00	?
Colombia	13,522	36	.36	0.98	5.10	?
Ecuador	4,007	28	.28	0.55	4.09	1.44
Peru	10,213	35	.17	1.17	6.85	?
Bolivia	3,311	34	.93	3.42	14.19	?
Chile	7,298	60	.76	.06	2.24	1.05
Brazil	62,725	36	.30	1.71	8.26	.55
Paraguay	1,677	35	.31	0.42	11.93	.33
Uruguay	2,700	—	.95	4.46	0.16	.61
Argentina	20,248	63	1.48	5.59	3.01	?

[a]1 Hectare = 2.47 acres
Data taken from: Statistical Abstracts of Latin America 1960, Center of Latin American Studies, University of California, Los Angeles.

This is only about half as much as we have per capita in the U.S.A., with our present population of about 180 million. To this in Latin America may be added another 1.88 hectares (4.64 acres) of permanent meadow or pasture

[1]Address given at banquet of the Weed Society of America, St. Louis, Mo., Dec. 13, 1961.

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