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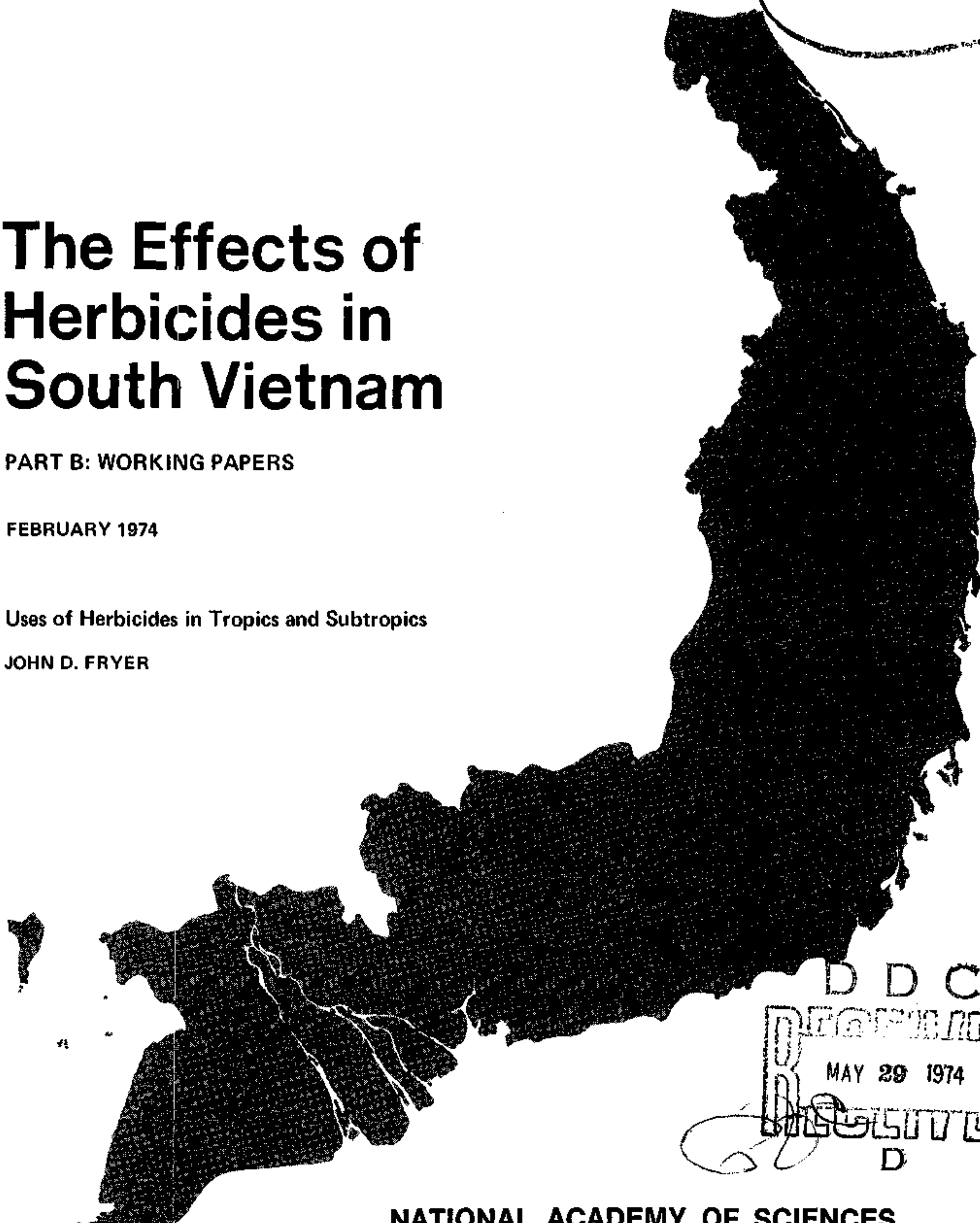
# The Effects of Herbicides in South Vietnam



PART B: WORKING PAPERS

FEBRUARY 1974

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JOHN D. FRYER



NATIONAL ACADEMY OF SCIENCES

# THE EFFECTS OF HERBICIDES IN SOUTH VIETNAM

## PART B: WORKING PAPERS

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## Uses of Herbicides in Tropics and Subtropics

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## Uses of Herbicides in Tropics and Subtropics

JOHN D. FRYER[a]

An impressive armory of chemical herbicides exists today, some of which can also be of value at low concentrations as plant growth regulators to enhance the performance of crop plants. More than 350 herbicidal compounds were included in the 1972 index of the journal Weed Abstracts. About 125 of these were listed in 1972 for practical use in the United States. This report reviews those that have found uses for weed control in the tropics and subtropics so as to place in perspective the herbicides that have been used for military purposes in South Vietnam (SVN).

It was not only in temperate countries that the new organic herbicides discovered in North America and Europe received an enthusiastic welcome. In the tropics and subtropics they were also eagerly tried out and rapidly put into practical use where they appeared to offer advantages over traditional methods of weed control--usually where crop production, processing, and marketing techniques were already highly developed. Herbicides were seen as a means of cutting costs by reducing the labor force and bringing further land under cultivation without employing more people. In East Africa, for example, the cost of weeding tea was halved by the use of herbicides and the labor force reduced by 60 percent. Moreover, many intractable weed problems that were at best only partly overcome by hand or mechanical control methods could be much more efficiently dealt with by the new chemical tools. In addition, revolutionary crop production

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practices were developed that increased efficiency and profit. The elimination of soil cultivation after planting sugarcane, pineapples, or tree crops, and the direct seeding of rice into uncultivated paddies are examples. Such practices revealed that herbicides are the key to crop production systems based on reduced or zero soil tillage which, in addition to saving power and labor, may provide ecological advantages such as maintenance of soil organic matter and soil fauna, and reduced erosion.

While herbicides quickly proved their value in developed agriculture in both temperate and tropical areas, they had little impact on small-scale farming, where family labor controlled weeds by hand and little cash was available for purchasing the chemicals and equipment to apply them. In vast areas of the tropics, chemical weed control has as yet no part to play in the lives of millions of subsistence producers. Nevertheless, wherever industrialization is beginning, and educational and agricultural development schemes are breaking the bonds of subsistence farming, herbicides are being welcomed as a means both of increasing profit and of allowing men, women, and children to occupy themselves in a more profitable and healthy way than the remorseless task of hand weeding.

## USE OF HERBICIDES ON CROPPED LAND

It is important to realize that 2,4,5-T, 2,4-D, and picloram, the constituents of defoliating Agents Orange and White used in Vietnam, are primarily selective herbicides and belong to a group of chemicals used with great benefit in agriculture and forestry the world over. Those that are most important for tropical and subtropical crops are listed in Table I,

**Table I.**

Herbicides used in tropical crops.

| | Cereals | Root Crops | Vegetables | Tree Crops | Other Annual Crops | Other Perennial Crops | Grassland and Forage Crops | Used Mainly for Control of: |
|---|---|---|---|---|---|---|---|---|
| **Acetamides** | | | | | | | | |
| alachlor | x | | | | x | x | | |
| allidochlor | x | x | x | | x | | | |
| diphenamid | | x | x | x | x | | | annual grasses |
| propachlor | x | | x | | x | | | |
| propanil | x | | | | | | | |
| **Anilines** | | | | | | | | |
| benfluralin | | | x | | x | | | |
| nitralin | | | x | | x | | | annual grasses |
| trifluralin | x | | x | x | x | x | | |
| **Arsenicals** | | | | | | | | |
| DSMA | | | | x | x | | | perennial grasses |
| MSMA | | | | x | x | x | | |
| sodium arsenite | | | | x | | | | trees |
| **Carbamates** | | | | | | | | |
| barban | | | x | | | | | |
| benzyldithio-carbanate | x | | | | | | | Annual grasses and broad leaved weeds also some sedges and perennial grasses |
| chlorpropham | | | x | | x | | | |
| di-allate | | | x | | | | | |
| EPTC | x | x | x | x | x | | | |
| molinate | x | | | | | | | |
| pebulate | | | x | | x | | | |
| propham | | | x | | x | | | |

Table I, continued.

| | Cereals | Root Crops | Vegetables | Tree Crops | Other Annual Crops | Other Perennial Crops | Grassland and Forage Crops | Used Mainly for Control of: |
|---|---|---|---|---|---|---|---|---|
| **Carbamates contd.** | | | | | | | | |
| **sulfallate** | | | x | | | | | |
| **tri-allate** | x | | | | | | | |
| **vernolate** | | x | x | | x | | | |
| **Phenoxy compounds** | | | | | | | | |
| **2,4-D** | x | x | x | x | x | x | x | |
| **2,4-DB** | x | | | | x | | x | |
| **2,4-DES** | | | | | x | | | |
| **2,4-DEP** | | | | | x | | | broad leaved woody and herbaceous weeds |
| **MCPA** | x | x | x | | | x | x | |
| **MCPB** | x | | | | | | x | |
| **2,4,5-T** | x | | | x | | x | x | |
| **dichlorprop** | x | | | | | | | |
| **mecoprop** | x | | | | | | | |
| **fenoprop** | x | | | x | | x | | |
| **Quarternary Ammonium Compounds** | | | | | | | | |
| **diquat** | | | | x | | x | | wide range of annual and aerial parts of perennial plants |
| **paraquat** | x | x | x | x | | x | | |

Table I, continued.

| | Cereals | Root Crops | Vegetables | Tree Crops | Other Annual Crops | Other Perennial Crops | Grassland and Forage Crops | Used Mainly for Control of: |
|---|---|---|---|---|---|---|---|---|
| **Triazines** | | | | | | | | |
| **ametryne** | | | | | | x | | |
| **atrazine** | x | x | | x | | x | | |
| **chlorazine** | | | x | | | | | **annual weeds and perennials at higher doses** |
| **desmetryne** | | | x | | | | | |
| **prometryne** | x | | x | | x | | | |
| **propazine** | x | | | | | | | |
| **simazine** | x | x | | x | | x | | |
| **terbutryne** | | | | | x | | | |
| **Ureas** | | | | | | | | |
| **chlorbromuron** | | | x | | | | | |
| **chloroxuron** | | | x | | x | | | |
| **DCU** | | | | | x | | | |
| **diuron** | | x | | x | x | x | | |
| **fluometuron** | | x | | x | x | | | |
| **linuron** | x | x | x | x | x | x | | **ditto** |
| **metobromuron** | | | x | | x | | | |
| **monolinuron** | | | x | | | | | |
| **monuron** | | x | | x | x | x | | |
| **neburon** | | x | x | | | | | |
| **noruron** | | | | | x | | | |
| **Uracils** | | | | | | | | |
| **bromacil** | | | | | | x | | **ditto** |
| **lenacil** | | | | | | x | | |

| | Cereals | Root Crops | Vegetables | Tree Crops | Other Annual Crops | Other Perennial Crops | Grassland and Forage Crops | Used Mainly for Control of: |
|---|---|---|---|---|---|---|---|---|
| **Miscellaneous** | | | | | | | | |
| **amitrole** | | | | x | x | | | **perennial weeds** |
| **ammonium sulphamate** | | | | x | | | x | **woody plants** |
| **bensulide** | | | x | | x | | | **annual weeds** |
| **bromoxynil** | x | | | | | | | " |
| **chloramben** | | x | | | x | | | " |
| **chlorfenac** | | | | | | x | | " |
| **chlorthal** | | x | | | x | | | " |
| **chlorthiamid** | x | | | | | | | **annual and perennial weeds** |
| **dalapon** | x | x | | x | x | x | | **grasses** |
| **dicamba** | x | | | | | | x | **annual and perennial broad leaved weeds** |
| **dichlobenil** | x | | | x | | | | " |
| **dinoseb** | x | | x | | x | | | **annual broad leaved weeds** |
| **DNOC** | | | x | x | x | | | " |
| **fluoridifen** | | | | | x | | | **annual weeds** |
| **ioxynil** | x | | | | | | | " |

Table I, continued.

| | Cereals | Root Crops | Vegetables | Tree Crops | Other Annual Crops | Other Perennial Crops | Grassland and Forage Crops | Used Mainly for Control of: |
|---|---|---|---|---|---|---|---|---|
| **Miscellaneous contd.** | | | | | | | | |
| **naptalam** | | x | x | | x | | | annual weeds |
| **nitrofen** | x | | x | | | | | " |
| **oils** | | | | x | x | x | | annual weeds grasses |
| **PCP** | x | | | | x | x | | annual weeds |
| **picloram** | x | | | | | | x | broad leaved herbaceous and woody plants |
| **sodium chlorate** | | | | x | | x | | all vegetation |
| **2,3,6-TBA** | x | | | | | x | | annual and perennial broad leaved weeds |
| **TCA** | x | x | | x | x | x | | grasses |

## Notes to Table I

An "x" indicates that a recommended and/or commercially-used herbicide treatment is available for one or more crops within the crop group and the herbicide concerned. Many treatments are not listed that show promise but are still under development. Some treatments may be specific to only a single crop within the group. The groups comprise the following:

| | | |
|---|---|---|
| Cereals | - | maize (corn), millet(s), rice, sorghum |
| Root Crops | - | arrowroot, cassava, ginger, sweet potato, tannia, taro, yams |
| Vegetables | - | bodi bean, cabbage, chickpea, cow pea, cucumber, dhal, dwarf bean, eggplant, green gram, guar, lablab, lentil, lettuce, lima bean, melon, okra, onion, pakchoi, pepper, pumpkin, tomato, urd |
| Tree Crops | - | avocado, citrus, cocoa, coconut, coffee, mango, oil palm, pawpaw (papaya), pimiento, rubber, tea |
| Other Annual Crops | - | castor bean, coriander, cotton, groundnut, jute, kenaf, safflower, sesame, soybean, sunflower, sunn hemp, tobacco |
| Other Perennial Crops | - | banana, grassland, pineapple, pyrethrum, sisal, sugarcane |

which also indicates the main groups of crops that can be treated with individual compounds. As explained in the footnote, many of the treatments are specific to certain crops and it is seldom possible for a particular herbicide to be used safely for all the crops comprising one of the crop groups in the table. Often the chemicals are highly specific and can only be used on a small range of crops under rigidly specified conditions.

## Cereals

MCPA and 2,4-D, first marketed in 1946, are still among the most successful herbicides because of their remarkable ability to control a wide range of broad-leaved weeds in cereals and other graminaceous crops at low cost of chemical, minimal risk of damage to the treated or subsequent crops, and--over a 25-year period--no detectable risk to the operator or the consumer. These compounds and their relatives are widely used in maize, millets, rice, sugarcane, wheat, and other tropical or subtropical crops, including grassland and tree crops. With continuing use, particularly in monoculture cropping, weed species--especially grasses--tolerant to these herbicides have tended to become more important. Several alternative chemicals with varied modes of action and specifications able to kill different weeds are now available to supplement the major compound. Some, such as 2,3,6-TBA and dicamba, are, like 2,4-D, applied to the foliage of the growing crop and the weeds. Others, like EPTC and triallate, must be applied directly to the soil before planting the crop. A few, such as atrazine, have both foliar and soil activity and may be applied to appropriate crops soon after emergence of the weeds.

Rice is of particular interest in view of its importance in the tropics, the wide range of varieties, the conditions under which the crop is grown, and the special herbicides that have been developed. Without chemical weed control, the present techniques of mechanized rice production would not be economically feasible. Several herbicides are now available that can be applied before the crop is planted, to minimize soil preparation and to kill weeds at an early stage. Paraquat is of particular interest because, being without residual activity in the soil, it can be sprayed after harvesting the previous crop to kill all vegetation in the paddy, thereby allowing rice to be sown or planted without any soil cultivation at all and allowing an extra crop to be taken through the time saved.

Herbicides for control of weeds in rice are most commonly applied after planting. For many years, 2,4-D, MCPA, and 2,4,5-T have been used for the control of broad-leaved weeds, sedges, and a range of aquatic weeds. At the concentrations used, they have not been found to be toxic to fish. In contrast, PCP, which is used extensively in Japan, represents a real hazard to fish not only in the paddies but also in the rivers into which they drain. 2,4-D and other herbicides have been found toxic at 1-10 ppm to Tolypothrix tenuis, a nitrogen-fixing blue-green alga found in some rice fields.

For the control of annual grass weeds in transplanted rice, either 2,4-D or MCPA in granular form is effective, as are PCP, nitrofen, and several newer herbicides. Propanil is the most important herbicide for controlling the same weeds in sown rice. Conditions for successful treatment are rigid, and adequate educational programs for users are essential. A number of other herbicides are also available for commercial use and many more are under test.

Corn, millets, and sorghum can all be treated with phenoxyacetic acid herbicides for broad-leaved weed control. Corn is exceptionally tolerant to simazine and atrazine and these herbicides, which are very effective against a wide range of broad-leaved and grassy weeds, are extensively used as soil treatments prior to crop emergence. Several other herbicides are available for special weed problems.

## Root Crops

Tropical root crops such as yams, sweet potatoes, cassava, and ginger are mostly grown in small patches and hand-weeding usually suffices. However, where local circumstances justify chemical methods, several herbicides have shown promise as an aid, if not the complete answer, to the weed control problem. A few examples are given below.

Cocoyam, Taro. Propanil can be used in paddy taro, as in rice, to give weed control early in the life of the crop. A variety of residual herbicides, including prometryne and chloramben, have been used successfully in upland crops.

Yams. Slow to emerge, yams require prolonged weed control after planting. Recommended preemergence treatments include 2,4-D, atrazine, TCA, and chloramben.

Sweet Potato. Where nutgrass and some other troublesome perennial weeds are a problem, EPTC or vernolate mixed into the soil can be used before planting if chemical control is required. After planting, several soil-acting residual treatments are available for annual weed control based on CDAA, chloramben, DCPA, diphenamid, EPTC, or naptalam.

Cassava. Promising results have been obtained with a range of residual herbicides but their cost seems likely to preclude their widespread use in this low-value crop.

## Vegetable Crops

Many herbicides are available. Most of these have been developed for areas where mechanized, large-scale crop production occurs, although intensive, small-scale vegetable growing in urban areas where labor is scarce or expensive may also justify their use. The more important crops in which herbicides are employed include: onions (chlorpropham, CDAA, nitrofen, and EPTC), peppers (trifluralin, chloramben, diphenamid, and DCPA), melons (bensulide, naptalam, DCPA, diphenamid, trifluralin), lettuce (CDEC, benefin, bensulide, pebulate, chlorpropham, propham), tomatoes (EPTC, pebulate, trifluralin, nitralin, diphenamid, bensulide, CDAA, CDEC, chloramben, DCPA), dwarf beans--*Phaseolus vulgaris*--(trifluralin, EPTC, DCPA, diphenamid, chloramben, CDAA, CDEC, dinoseb, linuron, monolinuron, metobromuron, chlorbromuron, dinoseb-acetate).

In many instances two or more of the above are combined as mixtures in order to widen the range of weeds controlled. In general, herbicide mixtures with as many as three or four components are becoming more widely used in many crops. This trend is likely to continue.

## Tree Crops

High-value plantation crops were among the first to be intensively weeded by chemicals. The scale on which they are grown, the profit consideration, shortage of labor, and the ravages of the war years in Asia resulting in invasion by perennial weeds on a vast scale, have all contributed to the outstanding need for and success of herbicides in these crops. In many instances the worst weeds are perennial grasses with vigorous and persistent creeping root systems that cannot be controlled by hand or mechanical methods except at very high cost and with extensive damage to roots of the crop plants. The use of herbicides covers all phases of plantation and forest development. Chemicals may be used in the nursery, for helping to prepare the ground for planting, to control vegetation during the vital establishment phase, for maintenance in the established plantation, and even for destroying trees when their useful life reaches an end.

For the most part, the same range of chemicals is used for the various crops. Paraquat is widely used for "burning off" the aerial growth of unwanted vegetation. Repeated use can keep all types of weeds under control, but for stubborn perennials herbicides with a greater degree of systemic action may be cheaper and more effective. For this purpose MSMA, dalapon, amitrole, and the phenoxyacetic acid herbicides are widely used. The first three are active on grasses, the last only on broad-leaved weeds. Once the initial weed cover is under control, and if bare soil is required either in strips or circles around each tree or over the whole floor of the plantation, a range of soil-applied herbicides belonging in the main to the triazine, urea, and uracil families (see Table I) provides a highly effective armory to prevent reinvasion. Where ground cover is required, herbicides can be of value in controlling the undesirable aggressive species, thereby favoring either a natural cover or the sown cover crop. Much remains to be learned about chemical control of ground cover and the potential is very great.

Tea. When land is being prepared for planting, the control of perennial grass weeds can be a serious problem and dalapon has been extensively used where cultural methods are ineffective or impracticable. Once the land is ready, it may be some time before planting can take place, and residual herbicides such as diuron or simazine are of value in preventing establishment of annual weeds. After planting and before sufficient cover has formed to shade out the weeds, simazine can again be used. Tea is highly tolerant to it. If contact with the young bushes is avoided, paraquat may be applied to tea as a directed spray to prevent establishment of weeds. Paraquat, simazine, and diuron can also be used for maintenance in established tea. Dalapon, monuron, 2,4-D, MSMA, and amitrole have also been successfully used as directed sprays.

Citrus. Perennial grasses, often found in citrus plantations, can severely reduce yields however frequently the area is cut over. Weed control using herbicides only has long been practiced in California and elsewhere with beneficial results. In recent years the cheap herbicidal oils used there and elsewhere have tended to be replaced by persistent, soil-applied triazine, urea, or uracil herbicides. Where necessary, amitrole, dalapon, MSMA, and phenoxyacetic acid herbicides can be used for control of resistant perennial weeds provided precautions are taken to avoid drift or excessive contamination of the soil. In citrus nurseries several herbicides can also be used safely, thereby greatly reducing or eliminating hand labor for weeding. Fortunately, citrus varieties as a whole have proved highly tolerant to a number of herbicides even at young growth stages.

Coconut. Since coconut is very sensitive to weed competition, ring-weeding of young plantations is essential and can be achieved by directed sprays of paraquat. Atrazine or diuron can be added to provide a longer period of control. Once the palms are fully established, further weed control is usually unnecessary. Old trees may be killed with sodium arsenite or 2,4-D.

Coffee. Young coffee can be treated in a similar way to coconut palms. However, established plantations are liable to become infested with a variety of serious perennial weeds for which hand and mechanical control methods are ineffective and can cause much damage to the crop roots. For these weeds dalapon or amitrole can often be successfully used. Paraquat, used as a directed spray, is invaluable for routine weeding and several residual herbicides may be safely used to prevent establishment of annual weeds.

Oil Palm. Unlike coconut palms, oil palms require a high level of weed control in the established crop in addition to ring-weeding of young plantations. In Asia, sodium arsenite has been much used for this purpose, sometimes with additions of dalapon and/or sodium chlorate. MSMA is very effective against perennial grasses. Paraquat is also of value. Atrazine, simazine, diuron, and monuron are recommended as residual treatments. Herbicides are also used to control weeds in oil palm nurseries, and for killing unwanted palms.

Rubber. Chemical killing of old rubber trees before planting is an important practice to reduce incidence of disease. Esters of 2,4,5-T, alone or mixed with 2,4-D, are applied mainly in diesel oil to the base of the trunk. This has been found more effective and safer than sodium arsenite, the traditional herbicide for this purpose. Young plantations are either weeded by hand or chemical methods. Most attention is given to the planting rows, which should be kept free of vegetation. Paraquat is widely used. Where perennial grasses are a problem, DSMA and MSMA are effective and even young rubber has proved very tolerant to these herbicides.

In established plantations, routine weeding of the planting strips may require only two sprays a year. Sodium arsenite at 10-20 lb/acre has been widely used in Asia for many years, as has sodium chlorate. In some areas, other herbicides have taken over: paraquat, dalapon, MSMA, amitrole, and 2,4-D. Very effective mixtures of these chemicals have been developed, particularly for perennial grass weeds; for example, MSMA + 2,4-D + sodium chlorate. Latex yield has been improved by widespread application of 2,4,5-T to rubber-tapping panels.

It may be of interest to record here that between 1950 and 1956, the Rubber Research Institute of Malaya conducted extensive investigations on the use of herbicides to defoliate rubber trees (*Hevea brasiliensis*) without killing them as a control measure in the event of an outbreak of South American leaf blight (*Dothidella ulei* P. Henn.). The *n*-butyl ester of 2,4,5-T was selected as the most effective of the chemicals tested and six large-scale aerial spraying trials were undertaken. From these it was concluded that 5 percent 2,4,5-T *n*-butyl ester in 3 gal gas oil/acre was the most satisfactory treatment, a single application resulting in complete defoliation within about 14 days of spraying. Treated trees remained free of leaves for 4 to 6 weeks (Hutchison 1958).

## Other Annual Crops

Apart from the root crops and vegetables already mentioned, a few other annual crops should be discussed in view of their importance and the intensive herbicide usage that has been developed in certain areas.

Peanut (Groundnut). As a preplanting treatment to control nutsedge and annual grasses, vernolate is recommended in the United States. A similar use has been found for benefin and trifluralin in Rhodesia and for fluometuron in the Sudan for grass control. Some of the phenoxyacetic acid herbicides have been successfully used for preemergence control of weeds, but crop damage can occur. Other herbicides in use include PCP, dinoseb, chloramben, naptalam, terbutryn, metobromuron, chlorbromuron, nitrofen, fluorodifen, and prometryne. Once the crop starts to emerge, the grower can use dinoseb reinforced by several other chemicals. 2,4-DB and MCPB may also be applied.

Soybean. This crop is well served by herbicides. Dalapon or amitrole may be used for controlling perennial grasses before planting the crop. Trifluralin and nitralin are also effective against grasses. After planting, a range of herbicides is available including chloramben, dinoseb, linuron, chloroxuron, DCPA, naptalam, fluorodifen, diphenamid, and others. The use of individual compounds and mixtures of herbicides for weed control in soybeans is still rapidly developing and recommendations vary from place to place.

Cotton. Chemical control of weeds in cotton has been highly developed in the U.S. and elsewhere. Preplanting treatments are based mainly on trifluralin and nitralin, but under some circumstances diuron, fluometuron and amitrole are of value. The use of amitrole is restricted in some countries. The principal herbicides used before crop emergence are diuron and fluometuron. A sophisticated system has been developed for the control of a range of serious weeds. A band of herbicide, e.g., EPTC, is applied on either side of the crop row at the same time as the crop is drilled, while a third band of a more selective treatment is applied over the row itself. In this way control of even difficult weeds like nutsedge can be obtained without crop damage. Once the crop has emerged, contact herbicides can be applied between the rows and weed control can be achieved by directed sprays of some substituted urea and triazine herbicides. Where grass weeds are a problem the organic arsenicals DSMA and MSMA may be used, as well as spot applications of herbicidal oils or dalapon.

Other Perennial Crops

In addition to the tree crops, there are a few other perennial crops grown extensively in the tropics in which chemical weed control has been developed to varying degrees. Of these, the two most noteworthy are pineapples and sugarcane, which in some countries are grown with such a highly developed and intensive use of herbicides that virtually no hand or mechanical weed control is required.

Pineapple. Dalapon may be used to clear up perennial grasses before planting, after which treatment a residual herbicide is applied to prevent establishment of weeds for several weeks. Repeat applications may follow as necessary. Herbicides used include diuron, simazine, atrazine, PCP, and bromacil. Spot spraying with dalapon using knapsack sprayers may be required for control of perennial grasses emerging during the life of the crop.

Sugarcane. In the wet tropics where much of the world's sugarcane is grown, weed growth is most intense when soil conditions make it difficult or impossible to control weeds by hand or machinery. Herbicides, therefore, play a vital role in this crop. The chemicals most commonly used are 2,4-D, substituted ureas, and triazines applied before the weeds emerge. After emergence, 2,4-D and directed (inter-row) spraying of dalapon, TCA, or paraquat can be used. In some areas the repeated use of 2,4-D over a period of some 25 years has resulted in increased populations of resistant strains of certain weeds. This is fortunately a rare and so far unimportant phenomenon in weed control in contrast to the resistance that can build up quickly in insects or plant diseases during control programs by chemicals. The wide range of herbicides that can be used in sugarcane is helpful in overcoming this problem and now includes, in addition to 2,4-D and the chemicals mentioned above: ametryne; atrazine; simazine; diuron; monuron; fenac; CDAA; 2,3,6-TBA; silvex; MSMA; oils plus PCP; terbacil; picloram.

Other perennial crops for which herbicide treatments are available include sisal, pyrethrum, and bananas.

## Grassland and Forage Crops

Tropical as well as many temperate grasslands are characterized by their liability to invasion by woody plants ranging from low growing shrubs to trees. Wherever a supply of seed of colonizing woody species is available, grassland can only be maintained if the pressures exerted on the invaders are sufficient to prevent them from establishing themselves or becoming too aggressive. These pressures may be from grazing animals, from the affairs of men, or as a result of natural phenomena, principally fires resulting from lightning. Changes in the use of grassland can quickly lead to conditions more favorable to the development of scrub or other weedy vegetation. As the density of human population increases, or, for example, a tsetse fly control program allows cattle into a formerly ungrazed area, intensive use by domestic animals can result in weakened growth of grass within a single season. A reduced grass cover, leading to weakened competition against invading scrub and less effective fires in the dry season, can quickly tip the balance in favor of woody species and within a few years a hitherto productive grazing area may become virtually worthless.

There has been much interest in and experimental work on scrub control by herbicides, principally 2,4-D, 2,4,5-T, and picloram. While these chemicals are extensively used for this purpose in some subtropical areas (principally the U.S.), they have only found restricted use in the tropical grassland. The principal reasons are cost, problems of application over the very large areas often involved, and the ability of some woody species to regenerate rapidly after treatment. In many tropical countries, particularly in Asia, the human population is such that wood of all kinds is a valued commodity and conservation of woody species rather than control is the problem. Moreover, some woody plants provide valued browse in arid areas.

One of the best known examples of herbicidal scrub control increasing productivity in subtropical grassland is that of mesquite (*Prosopis juliflora*), which in 1965 was said to cover 60 million acres in Texas and 20 million acres in Arizona. 2,4,5-T applied from the air at 0.3 lb/acre in 3 gal/acre diesel oil has been found to give a high level of control, although timing of the spray is very critical. Other scrub problems in the U.S. which have been successfully and extensively treated with 2,4,5-T or 2,4-D include species of Quercus (oak) and Artemisia (sagebrush). Economic studies have shown that increased production can quickly pay for the cost of treatment, and other benefits such as greater retention of ground water have been reported.

For smaller areas or for particularly resistant species, treatment of individual trees or bushes may be required either by spraying the foliage or soaking the base of the stem with an oil-based formulation of 2,4-D or 2,4,5-T.

In New Zealand, most of the sown pastures have been developed from subtropical rain forest. A few native species, principally Leptospermum scoparium (manuka) and many introduced woody species, tend to reinvade grassland. In Canterbury Province alone 250,000 acres of scrubland have been reported. Ulex europaeus (gorse) is the most important and widespread species, often covering large areas so densely as to eliminate grazing completely. Where plowing is not possible, spraying 2,4,5-T at 3-4 lb/acre, principally as ester formulations, is the standard control measure and has been practiced on a very wide scale for more than 20 years. Hand-lance spraying at high pressure (200-300 psi) is the most effective method of application, but hand-carried mist blowers and fixed-wing aircraft and helicopters have also been extensively used. Where 2,4,5-T has given unsatisfactory results, mixtures of 2,4,5-T with picloram or paraquat have been developed. In spite of the scale of treatment, the long period over which it has been practiced, and the lack of restrictions on use of the chemicals, undesirable side-effects do not appear from the published literature to have been of importance (Matthews 1960, Walton 1972, Williams and Palmer 1969). Gorse is also a problem in Hawaii, where successful results on it and many other woody species have been obtained with 2,4,5-T. Reports on the use of this herbicide, often mixed with 2,4-D for the control of a wide range of woody species in grassland, are available from many parts of the tropical world. Particularly intensive study has been made of possibilities for the chemical control of scrub in the vast savanna grasslands of east, central, and south Africa.

A few other herbicides are also effective against woody species. By far the most important is picloram, which has been commercially available since 1963. This extremely active herbicide is used in a similar way to 2,4-D and 2,4,5-T, applied either by air or to individual plants. It is effective on a wide range of dicotyledonous species at 1-2 lb/acre, but like the other herbicides has little effect on grasses except at very much higher doses. Picloram (Tordon 225) has recently been registered in the U.S. for use on pasture or rangeland. For local application to certain difficult-to-kill species or where spray drift is a special problem, ammonium sulfamate has proved very effective. High rates of TCA, dalapon, and sodium chlorate have all been reported to kill large bamboo clumps, which are difficult to deal with in any other way. Sodium arsenite is used extensively for tree destruction applied either to frill girdles at the base of the trunk or auger holes. It is cheap and effective.

It cannot be too strongly emphasized that herbicides can never be the complete answer to weed problems in grasslands, since their role in affecting such plant communities--usually consisting of many different competing species--is complex. The balance of species may also be easily upset by changes in the pattern of grazing, the use of fertilizers, by fire, by irrigation, and in many other ways. Herbicides must be regarded as just one factor, albeit a very potent one, in influencing the botanical composition. It is most important that their use be integrated with other measures aimed at improving the sward and preventing further invasions by weeds.

While this account has been confined to the control of woody species in grassland, the same herbicides and the principles discussed apply equally to the control of broad-leaved herbaceous weeds. Since legumes are extremely sensitive to picloram and to a lesser extent 2,4,5-T, these herbicides cannot be used in alfalfa or where the legume content of swards needs to be preserved. In such cases other phenoxy acid herbicides, especially MCPB and 2,4-DB, can be used. These chemicals, although they may be converted by some plants into the very toxic MCPA and 2,4-D, respectively, have little effect on many leguminous plants at the doses required for weed control. They, together with the contact herbicides dinoseb, ioxynil, and bromoxynil, can also be used safely for controlling weeds during the establishment of sown grassland and certain leguminous forage crops.

## USE OF HERBICIDES IN UNCROPPED AREAS

In the tropics, vast amounts of labor are required to keep vegetation of all kinds under control--not only weeds in cropped land, but also along roadsides, in gardens, under power lines, on railway tracks, around buildings, and in many other places. Control of the numerous plant species involved may provide much needed employment to local people, but there are many situations in which labor is either not available or is too expensive to allow maintenance to reach the desired standard.

The special problem of controlling aquatic vegetation cannot necessarily be solved by use of man and machines. Herbicides or, better still, biological control methods may be the only feasible course, particularly when large bodies of water are involved.

Total Weed Control

Where the elimination of all vegetation is required, as in storage yards or along railway tracks, several different chemicals may be applied according to the type of vegetation present and the need for economy. The use of sodium chlorate at 100-500 lb/acre has tended to give way to more modern chemicals that do not entail a fire risk. Moreover, its persistence is inadequate in the wet tropics. For initial kill of grasses, amitrole, dalapon, sodium chlorate, or paraquat may be used. Amitrole and paraquat will also provide an effective top-kill of most broad-leaved plants, but separate or simultaneous treatment with 2,4-D, 2,4,5-T, or picloram may be necessary. To provide long-lasting control a residual herbicide must be used at doses of 10-20 lb/acre to assure the chemical's long-term persistence in the soil. Appropriate herbicides include atrazine, bromacil, diuron, monuron, simazine, borates, dichlobenil, chlorthiamid. Cheap, effective sodium arsenite has been much used in the tropics, but of course is highly poisonous to man.

## Selective Suppression

The management of vegetation by chemicals, in contrast to its destruction, is still in its infancy. Mechanical cutting is by far the most common means of maintaining orderly plant growth along roadsides and in ornamental parks, gardens, and recreational areas. For rough, grassy areas, where cutting is impracticable, the growth retardant herbicide maleic hydrazide will keep the grass short and prevent its flowering. Where tall-growing broad-leaved vegetation is present, 2,4-D or 2,4,5-T may be added to the spray. Low doses of dalapon at rates of 2-3 lb/acre can also be used to check the growth of certain grasses.

## CONTROL OF AQUATIC VEGETATION

Of the many aquatic plants that can get out of hand in tropical fresh waters, the water hyacinth (*Eichhornia*) and the water fern (*Salvinia*) must be the most notorious. The former is found throughout the tropics and the latter has become particularly infamous since its remarkable spread during the early 1960's over 400 square miles of the surface of Lake Kariba in Africa.

While the use of herbicides can be very successful and has indeed been practiced on an extremely large scale (for example, 2,4-D for control of water hyacinth on the Congo and the Nile rivers in Africa and in Florida), there are many difficulties. Water in the tropics, as elsewhere, is used for many purposes: washing, drinking, irrigation, fishing, swimming, to list only a few. Herbicides may not only leave a residue in the water which may directly affect animals and plants, but through their ability to kill rapidly large amounts of vegetation, they may produce indirect side effects. One of the more important of these is deoxygenation of the water by decaying vegetation, resulting in the death of many organisms including fish. Safe, efficient use of herbicides usually depends on expert knowledge of the chemical, its fate in water, and its potential for biological activity, as well as an intimate awareness of the possible uses for the water being treated and the water courses downstream. Such expertise is scarce enough in developed countries and very rare indeed in the tropics. Clearly there is much scope for research and education on this subject in the tropics, where aquatic vegetation is found at its most luxuriant and the need to conserve and convey water for irrigation, drinking, and industry is often crucial.

Aquatic vegetation can be classified as emergent (the tall plants with often substantial aerial shoots arising above the water surface), floating, submerged, and bankside. This last includes any plants growing near water forming part of the system for which vegetation control is required. Some herbicides have been registered in the U.S. for safe use in and around water, provided that carefully defined precautions are rigidly followed (see Table II). In many countries, especially in the tropics, there are no regulations restricting the use of herbicides for aquatic weed control.

For a single-purpose water supply such as that needed for irrigation, where fish do not feature, more toxic chemicals may be acceptable. Aromatic solvents with or without PCP, acrolein, and endothall are examples that have been successful under tropical conditions.

Table II.

Herbicides registered in the U.S. for use in and around water.

<u>Herbicides registered for use in water</u>

| | |
|---|---|
| 2,4-D | silvex |
| diquat | acrolein |
| endothall | dalapon |
| copper sulfate | dichlobenil |
| xylene | dichlone |

<u>Herbicides registered for use adjacent to water</u>

| | |
|---|---|
| ammonium sulfamate | isocil |
| bromacil | MCPA |
| diuron | monuron |
| DSMA | MSMA |
| erbon | PCP |
| fenuron | petroleum solvents |
| fenac | sodium TCA |
| hexachloroacetone | TBA |

<u>Herbicides registered for use in mud bottoms after water draw-down</u>

| | |
|---|---|
| dichlobenil | monuron |
| diuron | xylene |
| fenac | |

A NOTE ON FORMULATION AND APPLICATION OF HERBICIDES

Herbicides are usually applied as sprays. Granular formulations are becoming increasingly popular for certain purposes (e.g., 2,4-D for rice), but still represent a very small proportion of total herbicide usage.

Herbicide products for spray application are normally supplied as aqueous concentrates, wettable powders, or emulsifiable liquids. Some herbicides, e.g., certain salts of 2,4-D and of picloram such as were employed in SVN in Agent White, are very soluble in water and therefore can be cheaply marketed as aqueous concentrates of the technical grade chemical. Surface-active agents may or may not be added. Other herbicides are virtually insoluble in water and in most organic solvents. These must be formulated as a wettable powder, consisting of the finely-ground compound, a filler such as talc, and surfactants. For use, the powder is "creamed" in a little water and then added, with stirring, to the water to be used for spraying. Emulsifiable liquids are suitable for herbicides that are freely soluble in inexpensive organic solvents. They consist of a concentrated solution of the herbicide in the solvent, in which is also dissolved a suitable emulsifying agent. When water is added, a stable emulsion is formed that can be easily sprayed.

Occasionally herbicides are used without any special formulation. Sodium chlorate is often supplied as the straight chemical applied either in solid form or dissolved in water. 2,4,5-T may be purchased by large-scale users as the technical grade compound (usually an ester) and dissolved directly in the oil in which it is to be applied, e.g., to kill trees by application to the base of the trunks. The 2,4,5-T and 2,4-D used in Agent Orange for defoliation in SVN were unformulated and applied as sprays of technical grade esters, which are liquid in their natural state.

The way in which a herbicide is formulated is mainly determined by its physical and chemical properties and the need to provide a stable and marketable product easy to store and to use. Since, however, activity and selectivity of herbicides can be much influenced by the method of formulation, special types of formulation may be developed for specific purposes.

Since herbicides are usually applied at doses of about 1 lb/acre of the active compound, it is necessary to dilute them with an inert carrier to make it possible to spread such a small amount evenly over such a large area. Water is usually used for spraying, but for some purposes it may be feasible to dilute the chemical with oil where it is in cheap supply. For solid formulations, various kinds of clay, chalk, or even sand may be used as the diluent. The amount of diluted spray used may vary from as little as 1 gal/acre for aircraft application to 100 or more for high-volume treatments applied by ground machines. Applications by tractor-mounted sprayers are often within the range 10-30 gal/acre.

Equipment used to spray herbicides is basically the same in the tropics and subtropics as elsewhere, ranging in size from small, portable knapsack units with a capacity of 3-4 gal spray solution and a single nozzle to powerful tractor-drawn sprayers carrying 150 gal or more and with multiple-nozzle spray booms up to 66 ft (20 m) in width. In the tropics, knapsack sprayers have a particularly important part to play even in large-scale estate crop work because they are cheap, easy to operate, and can be carried over difficult terrain. They are very widely used for all types of herbicides. For the large-scale treatment of crops like rice and sugarcane or of scrub-infested grassland, spraying is frequently done by aircraft, either fixed-wing or helicopter. For extensive areas of cropping where timing is critical, no other method may indeed be feasible. Their use is particularly appropriate to areas where one crop, e.g., wheat or rice, is almost exclusively grown at any one time so that the spray drift problem is minimal. Nevertheless, very extensive aerial spraying of herbicides is successfully carried out in many parts of the world where multiple cropping is practiced and the areas are relatively small. Whether or not drift becomes a major problem depends to a great extent on skill of the pilot and the ground crew and the method of application, but even more so on the prevailing meteorological conditions. The type of herbicide being applied is also important. Many soil-acting herbicides are inactive on even very susceptible crops once the latter are established, whereas low levels of drift of foliar sprays containing, for example, phenoxy herbicides, picloram, or paraquat may cause serious damage to susceptible crops, e.g., cotton and beans. At low doses most herbicides are selective in the plants they affect and even the very active herbicides may not have any adverse effect when drift reaches tolerant crops.

Spray drift is much influenced by the physical characteristics of the spray, small drops being very much more prone to drift than large. Drop size can be modified to a major extent both through controlling the spraying pressure and type of nozzle used and by combining certain additives with the spray liquid that affects its viscosity. Skillful combinations on the part of the operators virtually eliminate wind drift, except under the most unfavorable conditions. However, economics, logistics, lack of knowledge, and supply of equipment may all restrict adoption of such measures. Crop damage arising from herbicide drift is bound to remain a problem, albeit often a minor one, with most application techniques. It is certainly not confined to aerial spraying.

## CONCLUSIONS

Herbicides have been used effectively in most tropical crops and are applied on a very large scale in all parts of the world where there are developed systems of agriculture and forestry. They are also widely used on certain classes of uncropped land such as roadsides, railways, and industrial areas of all kinds. There is enormous potential for further development of chemical methods for controlling weeds and other vegetation.

It is unfortunately not possible either to indicate the total amount of herbicide used in the tropics and subtropics or to give information on the extent to which individual crops are treated. The statistics are not available. Information even on the overall usage of herbicides in different countries is sparse and sometimes of questionable significance. Data for some tropical and subtropical countries for 1970 are given in Table III.

Information from the same source serves to illustrate the rapidly expanding use of herbicides in the tropics. The FAO records show that in Taiwan the area of herbicide-treated rice increased from zero in 1965

Table III.

The use of herbicides in some tropical and subtropical countries, 1970.

(Based on figures in FAO Production Yearbook, 1971)

| | Pounds |
|---|---|
| El Salvador | 454,593 |
| Guatemala | 5,129,710 |
| Colombia | 6,590,050 |
| Ceylon | 129,411 |
| Israel | 1,335,779 |
| Jordan | 8,818 |
| Kuwait | 441 |
| Egypt | 145,505 |
| Ghana | 14,330 |
| Madagascar | 43,872 |
| Malawi | 2,205 |
| Mauritius | 1,694,030 |
| Sudan | 1,102,310 |

to nearly 8,900 acres in 1968 and that in India the amount of herbicides used increased by a factor of 40 from 1954 to 1967.

Expansion of herbicide usage in the tropics may be wholly desirable or should be viewed with some caution according to circumstances. On the one hand, chemical control methods can be extremely important in enhancing local and national economies and in assisting educational and development programs through the participation of those who would otherwise have to spend their time hoeing in the fields. On the other, the rapid adoption of herbicides by estates or large private land owners can cause hardship by reducing the labor force employed for weeding, a particularly serious problem in rural areas where alternative employment is not easily found. It must be remembered, however, that herbicides are not just an alternative to hand or mechanical weeding, but have many technical advantages that allow large and even revolutionary improvements in crop production efficiency. By making a more productive agriculture possible, they can help to bring long-term prosperity to a rural community and with it greater opportunities for employment.

## SUMMARY

Potential advantages of herbicides over traditional weeding methods in the tropics include:

1. Superior weed control and hence greater production and profitability even in situations of adequate human labor--e.g., difficult perennial weeds, avoidance of early weed competition and physical damage to crops, more complete weed control at times of temporary labor shortage.

2. Cheaper weed control in situations of inadequate and

expensive labor and where weeding requirements are particularly heavy.

3. Greater productivity resulting from ability to cultivate and weed a larger area with available labor or from ability to plant crops at optimal times.

4. Soil conservation--reduction of cultivation and hence of erosion and loss of soil organic matter.

5. Social advantages in releasing men, women, and children for more constructive activities.

Potential dangers of herbicide use include:

1. Economic

Danger to treated crops as a result of misuse by inadequately educated farmers--overdosage, incorrect timing, incorrect method of use. Danger to neighboring or following crops by drift or persistent residues, respectively. Both normally avoidable but risks greater with lower educational standards. Also danger from contaminated irrigation water.

2. Toxicological

Danger to operators (almost fully known for newer herbicides before marketing--generally very low indeed). Danger to consumers of produce (comprehensively evaluated for newer herbicides before marketing --hazard very remote, although not inconceivable, especially with low education.

3. Ecological

Damage to the soil microflora and fauna. (Studies so far suggest very little such risk. After detailed studies the Nature Conservancy in U.K. recommends 2,4,5-T for use in scrub clearance operations in nature reserves.) Danger to aquatic life from excessive or misuse (perhaps rather greater than in developed countries). (Dangers of "ecological" damage to plant life in general is little greater with herbicides than with any other means except that they can be more efficient. Agriculture itself is the main ecological factor.)

4. Social

Danger of reduced employment opportunities when large-scale farms use herbicides in preference to traditional methods (very few examples yet known but a danger to be guarded against so far as possible).

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