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STAFF SUMMARY REPORT

AQUATIC WEED MANAGEMENT IN THE GEZIRA CANALS

Wad Medani, The Democratic Republic of the Sudan

3 - 6 December 1978

Sponsored by

The University of Gezira, The
Democratic Republic of the Sudan

and

Board on Science and Technology for International Development
Commission on International Relations
National Academy of Sciences-National Research Council
United States of America

NATIONAL ACADEMY OF SCIENCES

Washington, D.C.

1979

This report is a staff-prepared summary of the Workshop on Aquatic Weed Management in the Gezira Canals, held in Wad Medani, Sudan, December 3 - 6, 1978, under the joint sponsorship of the University of Gezira, the Democratic Republic of the Sudan, and the National Academy of Sciences - National Research Council (NAS/NRC) of the United States. Participation by the NAS/NRC was made possible through funds provided by the Office of Science and Technology, Bureau for Development Support, Agency for International Development (AID) under contract AID/ta-c-1433. The University of Gezira will publish the final report of the workshop.

Contents

I

Introduction

In November 1975, the U.S. National Academy of Sciences National Research Council (NAS/NRC) and the Sudanese National Council for Research (NCR) jointly sponsored a regional workshop, "Aquatic Weed Management and Utilization in the Nile Basin." The subject of this workshop was the control and utilization of water hyacinth (*Eichhornia crassipes* (Mart.) Solms). Following the workshop, discussions were held between the BOSTID staff and Sudanese weed control specialists on the need for a workshop addressing the problem of aquatic weed management in canals. The Sudanese requested a workshop to consider canal weed management from the perspective of both short-term control and a longer-term program of integrated control.

Dr. M. Obeid, Vice-Chancellor of the newly created (1978) University of Gezira, offered to host the workshop at the University. This was an excellent location, since the University of Gezira is situated in Wad Medani, the center of the Gezira Irrigation Scheme. Agricultural products derived from gravity-flow irrigation are the economic mainstay of the Sudan, and the Gezira is the oldest and largest such system. Moreover, it is the engineering model for all other irrigation schemes in the Sudan. Wad Medani, approximately 100 miles south of

Khartoum, is on the western side of the Blue Nile. Water for the 900,000-hectares (2.2 million acres) Gezira scheme comes from the Sennar Dam on the Blue Nile.

The Sudan is basically an arid country, with only a small percentage of land mass suitable for plants requiring an aquatic or semiaquatic environment. It is in the canals of the irrigation schemes that favorable conditions are found for the often-observed "explosion" of aquatic weeds. The nutrient-rich, slow-moving, and often clear water from the Nile, coupled with seasonably warm weather and the high reproductive potential of certain tropical aquatic weeds, provides conditions that enable weeds to fill up canals in a relatively short time.

Weeds are commonly defined as plants that grow in a place where man does not wish them to grow, and plants growing in the canals of the irrigation schemes certainly fit this definition. Aquatic weeds are commonly defined as floating (e.g., water hyacinth), submersed (e.g., pondweed), and emersed (e.g., cattails). In irrigation canals the most serious problems are frequently caused by submersed weeds, which are the most difficult to control since they cannot readily be sprayed with herbicides and do not easily lend themselves to clearance by machines. In fact, herbicidal treatment must be applied to the entire volume of water for submersed plants, as opposed to surface treatment or spraying for floating and emergent plants. When canals are even partially filled with aquatic weeds, water no longer moves at the designated rate of flow, which increases loss through seepage, evaporation and transpiration, and ultimately reduces the supply needed for agricultural crops. The nearly stagnant water encourages mosquito breeding and enhances the habitat for bilharzia-carrying snails.

The canal system of the Gezira is broken down as follows: Main, Majors, Minors, Abu XXs, and Abu VIs. The Main canal, which draws water from the Sennar Dam, is 204 km long, 40 m wide, and 4.5 m deep. Branching off the Main canal are 987 km of Major canals, with an average width and depth of 10 x 3 m, respectively. There are 3,856 km of Minor canals, varying in width from 4 to 8 m and having an average depth of 1.5 m. The Abu XXs and VIs are the canals leading to the individual plots. Maintenance of the Abus, the responsibility of private farmers, varies according to individual whims. Maintenance of the Main, Majors, and Minors is the responsibility of the Ministry of Irrigation. However, because of their shape, size, and water velocity, there is no aquatic weed problem in the Main and Major canals, nor are they suitable for the vectors of malaria and bilharzia.

When one speaks of a weed problem within the irrigation schemes, then, the reference is to the Minor canals. There are 11,250 km of Minor canals in the Sudan, broken down as follows: Gezira (3,856 km), Menagil (3,958 km), Agricultural Reform (1,288 km), New Halfa (1,331 km), Suki (311 km), Tambul-Gunied (304 km), West Sennar (117 km), and Abu Naoma (85 km). All provide conditions that are advantageous for macrophytic aquatic weed growth because of their construction, design, nutrient load, and a slow rate of flow that makes them practically stagnant pools. Thus these canals are heavily infested with weeds anchored in the mud.*

Such aquatic weeds, interfering with water flows in the Minors, have become a serious limitation to the efficiency of the Gezira system of irrigation. Because the network of these canals provides the sole source of water to most of the people for drinking, cooking, bathing, washing clothes, fishing, and watering animals, the control measures undertaken must be compatible with the local conditions.

Aquatic weed control is carried out through one, or a combination, of the following methods: biological, chemical, mechanical or manual, and draw-down. The draw-down method kills off the aquatic vegetation by drying up the canals during the hot season (March - June). This technique is no longer

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*Including Potamogeton perfoliatus L., P. nodosus Prior, P. crispus L., P. pectinatus L., Najas pectinata (Porl.) Magnus, Chara globuloris Thillier, Ottelia alismoides (L.) Pers. and O. ulvifolia (Planch.) Walp.; also the banks of these canals are inhabited by emergent weeds such as Panicum repens L., Cyperus rotundus L., Ipomoea reptans Poir, I. aquatica Forsk, Echinochloa stagnia (Retz) Beauv., Phylo modiflora (L.) Greene, Cynodon dactylon (L.) Pers, Polygonum anyustoto Bory & Choub, Phragmites mauritianus Kunth, and Typha angustata Bory & Choub.

used because of the practice of intensive, year-round cropping that the Sudan adopted in the 1960s. In the past, manual clearing and draw-down of the canals in the Gezira were the techniques of choice.

Chemical control is relatively new, dating from the end of World War II. Mechanical control was not considered for a number of reasons, especially cost and the traditional reliance on manual and draw-down methods. Biological control is just starting to be actively researched and applied. However, with the intensive cropping of the 1960s, the irrigation scheme managers found that they were having to clean the canals on an average of eight times per year. With more than 11,000 km of canals, the costs were becoming prohibitive. Further, in the 1970s unskilled laborers found that they could earn as much as 30 times the daily wage for clearing canals by working in the neighboring oil-rich states. Thus, the irrigation scheme managers were faced with increased clearing demands and a reduced labor force.

The tendency was to turn to chemical control. However, this method requires special techniques, equipment, and trained personnel, as well as foreign exchange for the chemicals. Chemical control is further complicated because of the threat of contamination of adjacent commercial crops. Care must also be taken to protect the fish, animal, and human populations living in and near the waters being treated. Chemical treatment techniques vary not only according to the targeted plant species but also according to the rate of flow and the impurities in the water. Knowledge of life cycles, physiology, and reproductive characteristics of the weed species may provide clues to the proper timing for herbidical applications as well as for other control measures. For the most part, however, this basic knowledge is not available, and in fact an inventory of noxious weed species in the Gezira is just being completed (1978-79).

The advantages of chemical control are that dramatic results can be achieved within a few days (or less) of treatment and that costs are relatively low. Disadvantages of chemical control--in addition to environmental concerns--are that large masses of dead plant material may obstruct shallow canals, causing oxygen depletion and leading to further eutrophycation and subsequent regrowth of the same or other noxious species. In sum, chemical control does not solve the problems of canal clearing, but does lend itself well to treating emergency situations.

The managers of the various irrigation schemes are faced with increased demands for maintenance and difficulty in recruiting sufficient laborers. The remedies were herbicides with short-term efficacy and accompanying disadvantages; mechanical control with expensive equipment that offered little variety of choice; and largely untested and limited biological control techniques. It was in this context that the Sudanese turned to the NAS/NRC for assistance.

II

Agenda, Participants and Working Groups

The workshop was held from December 3 - 6, 1978, at the University of Gezira, Wad Medani. The first two days were devoted to background briefings by the Sudanese and discussions by the NAS/NRC panelists on the state-of-the-art of aquatic weed control in the United States. The third day was an all-day field trip to observe the Gezira irrigation scheme and its weed problem. For the final day of the workshop, the participants met in three working groups to discuss biological, chemical, and mechanical control techniques and to make specific recommendations for both the short- and long-term integrated control programs. Several general recommendations were also presented and collectively endorsed at the final session. Participation, open to the public, often resulted in considerable exchange among the participants and outside observers.

The University of Gezira hosted a reception Saturday evening, December 2. Each evening after the formal sessions and field trips, there were informal slide shows and talks by both U.S. and Sudanese participants on various aspects of the weed problem and control techniques.

The detailed workshop agenda follows:

Agenda

Sunday, December 3

A.M.

Chairman: Professor Hamid O. Burham, Director-General
Agricultural Research Corporation
Ministry of Agriculture

Opening Remarks - Dr. M. Obeid, Vice-Chancellor
University of Gezira

- Dr. David L. Sutton
Agricultural Research and Education Center
University of Florida

Refreshments

Paper: The Nile in the Sudan

- Dr. M. E. Beshir
Department of Botany
University of Gezira

General Discussion

P.M.

Chairman: Dr. David L. Sutton

Paper: Gravity-Flow Irrigation in the Sudan

- Mr. Kamal M. Abdu, Hydrologist
Agricultural Research Corporation

Paper: Crop-Water Requirements and Operation of Minor Canals

- Dr. O. A. A. Fadl, Soil Physicist
Agricultural Research Corporation

Discussion: Mechanical Control in the United States

- Mr. C. M. (Brate) Bryant
Aquamarine Corporation

- Mr. William C. Doering
Special Products Division
Lantana Boatyard

General Discussion

Monday, December 4

A.M.

Chairman: Professor M. Bakheit Said, Deputy Director-General
Agricultural Research Corporation
Ministry of Agriculture

Paper: Distribution of Aquatic Macrophytes in the Gezira

- Mr. A. M. Hamdoun, Weed Control Specialist
  Agricultural Research Corporation

Paper: Schistosomiasis in the Gezira

- Dr. Mutamad A. Amin, Faculty of Medicine
  University of Khartoum

Paper: Malaria in Irrigated Agriculture

- Dr. A. M. Haridi, Malaria Division
  Ministry of Health

Discussion: Chemical Control in the United States

- Dr. William T. Haller
  Center for Aquatic Weed Research
  University of Florida

- Mr. John E. Gallagher, Herbicide Division
  Amchem Products, Inc.

- Mr. Robert J. Gates, Special Support Division
  Southwest Florida Water Management District

General Discussion

P.M.

Chairman: Dr. M. Obeid

Paper: Past and Present Methods of Control

- Mr. A. M. Hamdoun

Paper: Biological Control by Fish

- Mr. T. T. George, Fisheries Research Center
  Agricultural Research Corporation

Paper: The Engineer's Viewpoint

- Mr. Kamal M. Abdu

Discussion: Biological Control in the United States

- Mr. William M. Bailey, Jr.
Arkansas State Game and Fisheries Commission

General Discussion

Tuesday, December 5

Field Trip: Gezira Irrigation Scheme

Wednesday, December 6

A.M.

Working Group Discussions

P.M.

Chairman: Dr. M. Obeid

Report: Biological Control

Report: Chemical Control

Report: Mechanical Control

Report: Summary & Recommendations

Thursday, December 7

A.M.

Departure from Wad Medani

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David L. Sutton (Chairman)

William M. Bailey, Jr. (Rapporteur)

T. T. George

A. L. El Moghraby

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C. M. (Brate) Bryant

L. A. Dessougi

William C. Doering

A. M. El Zubeir

Osman A. A. Fadl

III

Recommendations and Conclusions

The recommendations and conclusions that emerged from the three working groups (biological, herbicidal, and mechanical) are stated below. Since there were a number of similar recommendations from each group, the chairmen merged those recommendations and conclusions into a general category.

General Program Recommendations

The following general recommendations were made:

1. A national committee should be established and funded to work closely with the Ministry of Irrigation in planning and designing new irrigation canals, man-made lakes, and reservoirs, as well as to coordinate research and control operations for aquatic weeds and establish guidelines for the safe use of herbicides. This committee would in no way take over the duties and responsibilities of the Ministry of Irrigation but would help in planning research projects and implementing mechanisms for controlling aquatic weeds in the Gezira scheme.

2. The various government departments concerned with aquatic weed problems in the Gezira scheme should devote greater resources to research, education and control operations.

3. Intensive research should be carried out on the biology, ecology, taxonomy, and distribution of aquatic plants, and the information applied to improving weed control in the Gezira scheme. Additional studies are needed on biological control methods such as fish, insects, and pathogens. Also, studies should be made regarding the use of herbivorous snails which are not intermediate hosts of Schistosomiasis and feed intensely on aquatic vegetation, i.e., Marisa spp. Emphasis should be placed on screening herbicides (and their associated application techniques) to evaluate their effectiveness in relation to possible side effects. Testing should be conducted on the feasibility of mechanical control. In order to achieve long-range weed control objectives, a team of aquaculturists, engineers, entomologists, pathologists, ecologists, plant physiologists, and sociologists should undertake a research project over a period of 4 to 6 years. The outcome of such an investment could lead to a better understanding of the aquatic weed problem and an integrated and more effective management program.

4. The Ministry of Health, in coordination with the Ministry of Irrigation, the Universities of Gezira and Juba, the Gezira Board, and the Agricultural Research Corporation should conduct studies on the incidence and distribution of waterborne disease vectors, especially bilharzia and malaria. The life cycles of the vectors should be studied in relation to both the aquatic weed control techniques in use at present and those under consideration for possible future use.

5. The health, safety and welfare of people associated with the Gezira canal system should be considered in present and future weed control programs.

Recommendations on Weed Control Methods

The working groups made a number of recommendations that relate to studying or implementing various methods of weed control.

Biological Control--Short-term Activities

1. Population and behavior studies should be conducted on fish and other vertebrates in the canals to determine potential predators and to identify species of fish inhabiting the canals. The results will be useful for determining the size and numbers of grass carp fingerlings to be stocked and for developing an integrated aquatic weed management program.

2. Plant populations in the canals should be surveyed to determine the degree of weed infestation so as to evaluate the number of grass carp required for controlling weed growth. This information will also be used to pinpoint areas where the grass carp may not be effective and where other control techniques should be recommended.

3. Where suitable, canals should be stocked immediately with 5- to 6-year-old fish that are currently available. This will not only provide for the growth and development of fish

needed for brood stock, but will also enable a study on the effectiveness of grass carp for weed control. It will also provide information on stocking rates of mature grass carp that will be necessary for effective control of aquatic weeds.

4. Temporary brood-stock holding tanks with continuous water flow should be constructed for use in the spawning program until a hatchery is completed. (See recommendations below for construction of the hatchery.) A hatchery is urgently needed but is more properly listed under the long-term recommendations because of the time required to construct it.

Biological Control--Long-term Activities

1. A fish hatchery and rearing facilities should be constructed to provide an adequate supply of grass carp for stocking in the canals.

2. The grass carp and other fish from the canals should be studied for herbicide and insecticide residues to determine if they are safe for human consumption. If the pesticide residues are found to be within the tolerances set by the Government of Sudan, tenants should be allowed to harvest the fish after weed control has been achieved.

3. A study of native herbivorous fishes should be made to determine if native species might aid in the biological weed control program in the canals.

4. A study should be done on the feasibility of culturing fish in the canals to produce fish protein for human consumption. Aquaculture in the canals may not only provide an alternative source of high quality protein, but may also provide a means for controlling aquatic weed problems.

5. When rapid control of aquatic weeds is necessary, the control program should use herbicidal or mechanical methods, followed by biological methods for long-term control of regrowth.

6. Education and training should be provided to technicians regarding the spawning, culturing, and growing of grass carp.

7. Methods of applying insecticide to the fields should be improved to prevent their entering the canals (especially chlorinated hydrocarbons, which are persistent in the soil and build up in fish tissues, and organophosphates, which are highly toxic to fish).

8. There should be increased cooperation between the agencies associated with the Gezira and other schemes to ensure that all efforts are coordinated toward the effective management of weed problems in the canals.

9. Biological control agents, other than the grass carp, should be studied for their potential inclusion into an integrated aquatic weed control program.

Herbicidal Control

1. Herbicides should not be used for aquatic weed control in canals near villages or settlements of immigrant laborers, as these canals are often very heavily used by the people.

2. Only the safest herbicides should be used for weed control in the Gezira. Consideration has been given to the human use of water, to fish and wildlife populations, and to irrigated crops. The proper application and use of herbicides recommended (which have passed the United States' Environmental Protection Agency's standards) should not be detrimental to any aspect of the Gezira.

3. The use of herbicides in aquatic weed control and their effect on irrigated crops has not been studied in the Sudan. It is imperative that a herbicide research program of this type be initiated in the Sudan for ascertaining the optimum use and limitations of herbicides in the Gezira.

4. Educational programs to train scientists in aquatic weed control should be rapidly expanded. Such programs should provide for scholarships, research programs, and exchange visits between U.S. and Sudanese scientists involved in aquatic weed control.

5. A herbicidal aquatic weed control pilot project should be initiated involving the Ministry of Irrigation, the Gezira Board, Agricultural Research Board, and scientists from the

Table 1. Recommended Herbicide Treatments for Aquatic Weed Control in the Gezira Scheme

Plants	Location	Herbicide	Concentration	EPA Tolerance Potable Water	Comments
Submersed Weeds	Remote Minor canals	Diquat Endothal	1 ppm 1-2 ppm	0.1 a	See text. Aquathol-k
Emergent Weeds	Mains, Majors, near villages	Glyphosate	1 gallon/acre	b	Very safe to use on emergent weeds, no herbicidal effect expected in irrigation water.
Emergent Weeds	Minors AbuXX	Glyphosate Dalapon Diquat or (paraquat) Amitrol T.	as on label	b c 0.1	Foliar sprays usually result in very little herbicide in water. These chemicals should be safe used in close proximity to crops in AbuXX. Drift control and surfactants will be beneficial. Spray dry Abu xxs for maximum safety.

a. Tolerable levels of endothal in drinking water (potable water) in the United States have not been established by the Environmental Protection Agency (EPA). However, a tolerance of 3 ppm is being requested by the chemcial industry. Current labels of endothal products prohibit the use of treated water for irrigation until 7 days after treatment.

b. Glyphosate is a new herbicide and tolerance limits in potable water have not yet been established. However, Glyphosate is very biodegradable, has low toxicity, and levels occurring in water near sprayed emergent plants will be insignificant.

c. Dalapon does not have a tolerance in potable water. Its tolerance in irrigation water in the western United States is 0.3 ppm. Foliar treatments, particularly spot treatments, of Typha and other emergent vegetation, would generally result in concentrations much less than 0.3 ppm in the irrigation water.

University of the Gezira. This pilot project would also include studies of the weed biomass through vegetation surveys, as well as monitoring the uptake of herbicides and their fate in the aquatic ecosystems.

Long-range Herbicidal Research

Some urgent needs in the chemical control program have been detailed earlier, including education and the testing of the herbicides listed in Table 1. Effective control programs will require modification which can only result from continuing research. Project managers should always be looking for better techniques, additives, spray timing, and other improvements that will result in safer, more effective, and economical weed control. The following list includes items that should be undertaken in conjunction with the development of a program.

1. Chemical recommendations in this report are designed to minimize herbicide levels in the irrigation water. The herbicides recommended are low toxicity chemicals with a short residual half-life, but they are also expensive. Experimentation with other herbicides under Sudanese conditions could result in the discovery of more effective application rates, timing or combinations of compounds.

2. Spray additives could immediately improve the control programs. Raindrop nozzles and drift-control additives would

reduce drift danger to crops and result in more herbicide on the target plants. The rapid drying of water mixes and slow uptake of herbicide by emergent plants could be alleviated by adding oil surfactants to the tank mix.

3. Studies on draw-down treatments could also improve weed control programs. Initial tests could be conducted in drainage canals.

4. Biological studies, basic life history studies, and monitoring studies should be carried out to determine the effectiveness of the control program. Such studies could also pinpoint ideal times to spray the vegetation. For example, split applications of glyphosate have controlled *Typha* and phragmites for two years or longer in the United States.

In sum, the herbicide working group concluded that chemical weed control programs can solve *some* of the problems in the Gezira scheme. Contamination of water used intensively for agriculture and domestic purposes is an obstacle that can be avoided by careful planning and proper herbicide selection and application. Training of weed control personnel, project managers, and additional scientists is needed. Chemical aquatic weed control projects in the Gezira can be started immediately and a full-scale, very effective program can be in full operation within a few years if both the authorities and the public recognize the weed problem and become dedicated to its solution.

Mechanical Control

1. A one-year study should be conducted to compare various mechanical means for controlling aquatic weeds. The goal of the study should be to determine:

- Efficiency (cost of treatment per kilometer per day);
- Frequency of weed removal operations;
- Adequacy of local skills for operating machines;
- Operating costs and down-time;
- Availability of spare parts;
- Initial costs;
- Total system costs;
- Life in years; and
- Cost/benefit ratio.

2. Until the study is completed and the most suitable mechanical method selected, current manual removal methods should be continued. It is recommended that refinements be added, such as protective clothing for workers.

3. Experiments with canal design, e.g., deeper and narrower canal cross-sections, that will deliver the same volume and velocity of water should be conducted. With new canal design, it may prove possible to move the same volume of water at comparable speeds but with reduced growth of aquatic macrophytes.

IV

Working Group Reports

Biological Control

Biological control agents are defined as those organisms that effectively reduce the growth of target species. The goal in biological weed control is reduction of plant growth to an acceptable level, not eradication of the weed. A balance must be achieved that will permit enough plant growth to maintain the control organism and enough control organisms to maintain the weed growth at a low level. One of the principal benefits of this balance is that once it is achieved, weed control will be maintained for a number of years with little cost for additional control units, though occasional restocking may be necessary.

Various methods of biological aquatic weed control have been tested, but with only limited success. One of the few exceptions has been the use of arthopods for control of alligator weed (*Alternanthera philoxeroides*). Another exception is the grass carp, also commonly called the white amur (*Ctenopharyngodon idella* Val.), which is one of the most promising organisms for the control of a number of aquatic weeds, especially submersed ones such as *Potamogeton*, *Najas*, *Ceratophyllum*, *Cabomba*, *Utricularia*, *Elodea*, and *Hydrilla* species, some filamentous algae, including *Pithophora*, *Chara*, *Nitella*, and *Spirolyna*, and floating plants such as *Lemna* or *Wolffia*. Weeds that have not been controlled by biological means under field conditions include most of the emergent plants such as *Typha*, *Eleocharis*, *Brasenia*, *Scirpus*, *Orontium*, *Phragmites*, *Polygonum*, *Cynodon*, *Cyperus*, *Ipomoea*, *Phyla*, and *Echinochloa*. Experimental results suggest that some of these weeds might be biologically controlled with insects, pathogens, and competitive plants, but these controls have not yet been proven in actual wide-scale practical application.

NOTE: There are some sites where specific biological controls should not be used and where the biological control organism may pose a threat to the aquatic site, the terrestrial surroundings, or to the people who are associated with it. For example, in canals--especially elevated canals--muskrats, crawfish, or other burrowing creatures should not be used. Competitive plants, such as the dwarf spikerush should not be used in areas where they might become competitive with crops, or where the plant itself might provide an excellent habitat for the snails that are vectors for bilharzia. Also, in some areas there may be a unique natural fauna that should not be disturbed by the introduction of a new species.

Capital outlay required for developing a new, unproven biological control organism may be very high, and the required exploratory research is time consuming and expensive. Once an organism is identified, it normally is placed in a quarantine while additional research is conducted. The effect upon the target species is studied extensively. If the organism proves effective, then its effects upon non-target species and the environment must be studied. Production costs must also be considered to determine if this method is practical for field application. These studies usually require years and may actually cost millions of dollars.

Based on past experience in the United States and other countries with grass carp and the alligator weed flea beetle as biological control agents, it is clear that the time between the initiation of research and actual placement of the organism in the field requires considerable time (9 to 10 years). The actual time spent in search of a specific organism may be far longer. Therefore, it is more practical at this point to consider the work done in other systems and then apply this knowledge to the problems in the Gezira. This approach will reduce much of the time and expense involved in initiating a biological control method. Furthermore, decades of research might not uncover more effective biological control organisms than the ones that are being considered for the Sudan. Experience shows that once biological control programs are in operation, they are generally the least expensive alternative for pest control.

The ideal situation would be one where the control organisms reproduce in sufficient numbers to effectively reduce plant growth, but do not reproduce to the extent that all plants are eliminated and none are available for further generations of the organisms.

Excessive aquatic weed growth in an ecosystem will accelerate silting, as well as slowing water flow, causing flooding, and increasing evaporation losses. Foliage breaking the water surface enhances mosquito production by protecting mosquito larvae from wave action and fish, thus interfering with mosquito control procedures. Weeds also harbor the vector snails of bilharzia, which find admirable shelter habitats among them, with rich supplies of food and suitable surfaces for oviposition.

Weeds can be eradicated by the use of herbicides, but many problems are associated with their use. They are generally only partially effective, their efficacy is temporary, and they are very expensive. They also have unknown effects on the environment, particularly with regard to residue persistence in water, bottom mud, and fish and shellfish. There are no such fears of contamination with biological means. Further, biological agents are far less expensive and have a longer-lasting control effect.

One of the major benefits of using the grass carp for biological control is that the weeds may be converted into useful protein. The grass carp may convert as much as 80 percent crude protein on a dry weight basis, a benefit that is lost when alternative methods of weed control such as with herbicides and mechanical methods are used.

Biological control is more gradual and is less likely to cause oxygen depletion, which may kill other living organisms.

Biological control also causes less physical disturbance of the habitat than mechanical controls. Moreover, it fosters a more suitable environment than other control methods for introducing still other biological agents to reduce mosquito larvae. Although any type of weed control should reduce mosquito populations and make remaining larvae more vulnerable to mosquito fish (*Gambusia affinis*) or other natural predators, chemical and mechanical controls may also reduce the mosquito fish and other natural predators through oxygen depletion or by mechanical damage.

When considering biological control, it is necessary to weigh not only the benefits but the disadvantages as well. For instance, the known biological agents will not control all types of aquatic weeds. Agents have not yet been discovered that are effective against emergent weeds of the Gizera such as *Typha angustata* or *Phragmites mauritianus*. Further, grass carp will not reproduce under Sudanese conditions without hormone injections requiring skilled personnel and special equipment. The need for special equipment and trained manpower, however, generally also holds true for chemical and mechanical control techniques.

The weed control program using grass carp could be seriously set back or destroyed by inadvertent spillage or spraying of pesticides in the canals of the Gezira. Care must be taken to assure that highly toxic chemicals do not enter the canals.

When using a biological control agent, it is necessary to rely upon the characteristics of the control agent to achieve the desired goal. Man, therefore, cannot maintain total control of either the agent, the process, or the extent of weed removal. This lack of complete control is in some ways similar when chemicals are used, whereas with mechanical methods, the desired degree of control may be more easily achieved and maintained.

Of the available, proven biological control agents, only the grass carp (Ctenopharyngodon idella) readily fits the needs in the Gezira scheme. In some situations, common carp (Cyprinus carpio) have also been used successfully to control aquatic weeds. They appear to be especially useful in bodies of water with mud bottoms. Common carp in sufficient numbers increase the turbidity of the water, thus reducing plant growth by shading. The common carp might be considered as an addition to the control method if it is acceptable in the Gezira scheme.

Aquatic plants present in the Gezira canals that can be controlled by the grass carp include all the submersed species. Cattails, the major emergent plant, probably cannot be controlled by grass carp.

The use of grass carp for weed control in the Gezira has a number of potential benefits that should be considered in making a final choice of control method. These are discussed below:

- Use of grass carp for weed control has proved to be relatively inexpensive in other countries.
- Grass carp converts excess plant biomass into a useful product, fish protein.

° Use of grass carp will reduce the need for other control methods. Carp may be particularly effective in inhibiting plant regrowth when used in an integrated control program with herbicides and mechanical methods.

° Grass carp will give long-term control of submersed weeds due to the long life span of the fish. In some areas control has been achieved for as long as 8 years with a single stocking of fish.

° Weed prevention is also possible using grass carp. A small number of the fish, three to five per acre stocked in canals that do not have plants, may prevent weed growth.

° Grass carp consume all exposed plant matter, thereby reducing the habitat for disease vectors. The addition of common carp, which root plants and consume snails that carry bilharzia, might be a further aid. Weed control will also reduce breeding areas for mosquitoes and will enable the mosquito fish, <u>Gambusia affinis</u>, to more easily prey upon the mosquito larvae.

° The actual cost of aquatic weed control by grass carp may be completely offset by the value of the fish as an end product. When this value is added to the other general benefits of weed clearance the cost/benefit ratio of weed control with grass carp may be particularly favorable.

Herbicidal Control

The major problems noted in the Gezira were submersed weeds (Najas, Potamogeton, and Ottelia species), primarily in the Minor canals, and various grasses (Typha, Panicum and Cyperùs species) in smaller Abu XXs. The submersed weeds constitute a favorable habitat for bilharzia snails, and the shallow standing water in the Abu XXs provide excellent habitat for malaria vectors. Further problems caused by these weeds are a serious reduction in water flow and increased loss of water by transpiration and evaporation. Research conducted in the United States has shown that when water is slowed down and made stagnant by submersed weeds, the surface water becomes very warm and evaporation rises significantly.

In making recommendations for major aquatic weed control programs, it is desirable for planners to know the cost/benefit ratio to determine whether a particular control effort can be economically justified. The herbicide committee was therefore interested in research efforts that would help determine the economic losses caused by aquatic weeds, particularly studies to determine: the reduction in worker productivity due to aquatic-borne diseases, the value of reduced crop yield as a function of water losses through evapotranspiration, and projected losses from reduced agricultural expansion.

Generally, weed control methods are divided into three traditional approaches: biological, chemical and mecnanical.

The herbicide working group stressed the need for an additional approach--prevention. Current weed problems appear to be resulting from native aquatic plants, but the problems would likely increase dramatically if exotic aquatic plants were introduced--whether advertently or inadvertently--into the Gezira. Gezira authorities and national authorities should work together to prevent the introduction of alien aquatic plants such as Hydrilla verticillata, Myriophyllum spicatum, and others into Sudan. The Gezira habitat appears favorable for explosive growths of Hydrilla, a plant which is spreading rapidly throughout the world. The Ministry of Irrigation has an active program for preventing hyacinths from entering the Gezira. This aspect of weed control should be recognized by the authorities, and national laws should be passed or enforced in order to prevent entry of potentially noxious aquatic plants into the Sudan.

NOTE: Herbicides of various types are available for controlling all the weeds in the irrigation canals of the Gezira. However, local inhabitants utilize the water for domestic purposes, including bathing, drinking, and watering livestock. Consequently without a major educational program the use of inexpensive but toxic herbicides, such as acrolein, is not possible in the Gezira. Herbicides should not be used for submersed weed control (total volume treatment) in canals near villages or settlements of immigrant laborers, as these canals are often very heavily used by the people.

Remote Minors containing submersed weeds may be considered for treatment with herbicides (Table 1). Certain precautions can increase the safety of their use. The slower the water flow, the more effective control will be. An ideal situation would be one where water flow can be stopped for 48 hours after treatment. Although the herbicides recommended will be effective in slow moving water, the advantages of stopping the flow for 48 hours are:

1. The herbicide remains were it is applied;

2. Treatments at initial concentrations will be absorbed and adsorbed by plants and soil. Physiochemical and biological degradation will begin resulting in much lower herbicide levels in the water after 48 hours; and

3. Herbicide treatments in non-flowing water generally give better kill of aquatic weeds.

Because the herbicides recommended are contact foliar sprays, and newly germinated crop plants may be adversely affected or killed if covered with irrigation water containing contact herbicides, a safer method for application of herbicides to submersed weeds is to introduce the chemical when the irrigated crops are several centimeters tall.

Emergent plants are easier to control, and fewer potential hazards exist than with chemical treatment of submersed weeds. Emergent foliage is usually sprayed with a herbicide mix placed on the target species; with proper application, little or no residue is found in water near the treated plants.

The herbicides recommended in Table 1 are the safest to use in irrigation and domestic water schemes. Spot-treatments in Major, Minor, and Main canals, even in village areas, will not endanger the public. Treatment of the Abu XXs will be most effective and safest to crops if they are drained before herbicide treatment.

The chemicals recommended have low mammalian toxicity and, so far as is known, will not have adverse effects on irrigat- crops if properly applied. The major hazard of herbicide use is to the individual mixing the chemical concentrates for spraying the canals. Label precautions and proper application techniques will result in minimal hazards to the operator. The chemicals recommended are nontoxic to fish if applied properly; however, low oxygen content in water will occur periodically when treating submersed weeds and minor fish kills can be expected. These can be minimized by treating only a portion of the Minor canals at one time (leaving untreated areas that will continue to produce oxygen). Treatment of emergent vegetation should never result in fish mortality. Judgment and experience will enable herbicide applications that will affect the environment to the smallest extent possible and yet provide for maximum control. Proper training and supervision is essential for the health and safety of the operating personnel, to avoid damage to crops and fish populations, and to adequately protect the health of human and animal populations.

The herbicide working group has recommended the safest chemicals for weed control in the Gezira based upon the multi-use nature of the water in the canals. Careful consideration has been given to the people drinking and using canal water in the Gezira, to fish, wildlife, and animal populations, and to irrigated crops. Proper application and use of the chemicals should result in considerable economic and social benefits, and should not be detrimental to any aspect of life in the Gezira.

The use of chemicals for weed control can be initiated immediately and can be continued until alternative control measures are satisfactorily worked out. The risks of not controlling weeds in the immediate future are:

- Weed problems are burgeoning in the Gezira scheme, concurrent with labor shortage and intensification of agriculture.
- Disease problems associated with aquatic weed populations will increase unless aquatic weed control programs are begun immediately;
- Increased crop productivity in the Gezira is limited by aquatic weeds that slow or stop water flow and increase sedimentation; and
- Semiaquatic ditchbank weeds such as *Dichanthium annulatum* will spread and cause further problems.

Research and monitoring mechanisms should be established at the time of initiation of herbicide control programs. Herbicide movement in canals can be monitored with dyes. Time of contact and herbicide rates should be studied. Herbicide residues should be tested to study the effects of low herbicide concentrations on growth and production of irrigated crops. Literature searches and new information on new and old herbicides should be collected. Soil-applied herbicides such as fenac and dichlobenil as well as various ureas and triazines should be studied for their effectiveness in long-term weed control in drainage canals. Research on dried Minors could also be considered. Life cycles and distribution of aquatic plants in the Gezira should be studied to determine the optimum time for applying herbicides and to provide a data base for future evaluation of the chemical control program.

In sum, it is the opinion of the herbicide working group that the benefits of aquatic weed control by using herbicides greatly outweigh any potential adverse risk or effect on the people, livestock, and wildlife of the Gezira.

Mechanical Control

Mechanical methods are currently the dominant methods of control in the Gezira canals, including chain-like saws pulled manually across the canals and draglines operated wherever it is necessary to desilt a canal. At present, there are 70 dragline units operating in the Gezira scheme. These units are doing a satisfactory job of relieving the canals of their silt load and of removing the aquatic weeds in the process.

Both submerged and emergent species can be controlled by mechanical means. It is envisaged that mechanical methods could be operated, in the Gezira canals, either from the canal banks or on the water surface. However, the engineering structures in the canals, called reaches, pose some problems for waterborne mechanical systems. On the other hand, though control units operating on canal banks would not be limited by physical barriers they may, depending on the type of machine, require a smooth graded surface in order to operate without interruption.

Because of these limitations, it is envisaged that a waterborne mechanical system might consist principally of suitable transport equipment, a crane, and a control unit. On the other hand, a ground system would require a scraper service unit in addition to a self propelled control unit.

These two types of control systems are envisioned only for weed removal. Silt removal is adequately taken care of by the present fleet of draglines, and there appears no urgent need for procurement of other equipment to replace this method.

To adequately evaluate the two systems of weed removal, it is suggested that an experiment be initiated to compare various units of the two systems with respect to:

* Output in ha per day;
* Rate and frequency needed for weed removal;
* Quality as percent removal;

- Matching of local skills to machine;
- Running costs;
- Availability of spare parts;
- Initial cost;
- Total system cost; and
- Life in years.

This comparison will enable sound choice of a system. It will be advantageous if a number of different schemes can be included in the trial so that the various types of systems available at present can be judged under local conditions. In addition to the above criteria, the experiment will enable the determination of a cost/benefit ratio that can be used as a basis for comparison with other methods.

V

Observations and Comments

The basic purpose of the workshop was the exchange of information and experience between U.S. and Sudanese participants. The workshop met this purpose well. Approximately six hours of formal sessions were held each day, and informal sessions after the meetings were equally long. Each U.S. participant brought slides of pertinent weed control activities and distributed extensive literature and abundant samples of herbicides and application equipment. The professional competence of the U.S. panelists was evidenced by the fact that three of them were invited to remain for consultation after the workshop ended.

Overall attendance at each formal session was 15-17 people, and the quality of background papers and participation was high. Most of the outside participation was from "the environmental side" (mostly Europeans and Americans), who generally endorsed biological control and damned chemical control. Having heard all sides, the working groups met in closed session on the final day to prepare their reports which were subsequently presented in an open session.

The University of Gezira, under the dynamic leadership of Dr. [illegible], is playing a leading role in coordinating weed research in the Sudan. The University is sponsoring a symposium on weed research late in 1979 and hopes to establish a weed

Research Institute. There is every reason to believe that this will happen, and support should be given to the University in this regard.

The workshop pulled together a wide range of Sudanese officials concerned with weeds, health, and engineering factors in irrigation schemes and highlighted the need for greater coordination and communication among those concerned. The meeting further established a dialogue that will likely continue between the United States and Sudan. Fianlly, weed research has received relatively little attention in the Sudan (beyond control of the water hyacinth in the Nile). It is anticipated that the workshop will increase the Government of Sudan's commitment to this important but largely neglected aspect of health and agricultural development.

BOSTID Staff Support

Rose Bannigan and Dennis V. Wood, of the BOSTID staff, coordinated NAS/NRC participation in the workshop.

Mrs. Bannigan and three of the panelists (William M. Bailey, William T. Haller, and David L. Sutton) spent two days in Cairo observing the biological weed control activities that Dr. Bailey and Richard [illegible] had initiated in 1975 through BOSTID funding. Dr. Bailey and Dr. [illegible] provided the Egyptians with [illegible],000 grass carp fry and a quantity of spike-rush seed respectively. The observations, discussions, and recommendations were reported in Mr. Bailey's Trip Report to BOSTID, dated February 12, 1979.

While the panelists were in Egypt, Dr. Wood was in Khartoum coordinating workshop details with the University of Gezira and USAID and met with the USAID Director, Gordon Pierson, and the Food and Agriculture Officer, Raymond Carpenter, to discuss the details of the workshop. USAID was unable to provide participants to the workshop because of concurrently scheduled activities. However, AID/Washington was represented by Fred Warren. Dr. Wood also met with various officials at the National Council for Research for preliminary discussions on future cooperative programs and to make arrangements for in-depth discussions after the workshop.

Following the workshop, Drs. Sutton, Warren and Wood, and Mrs. Bannigan met with Mr. Pierson and Dr. Carpenter to summarize the events and recommendations of the previous four days. Both Mr. Pierson and Dr. Carpenter were interested in the workshop and the recommendations, especially in the principal biological control method suggested (use of the grass carp). It was the consensus of the group that support for Mr. T. T. George's efforts in general, and for a fish hatchery in particular, merit further consideration. Subsequently the group also discussed with Dr. Carpenter the possibility of an Advisory Group on Weed Control in Agricultural Systems (aquatic and terrestrial). The BOSTID staff stated that the NAS might find it possible to provide funds and organizational support for such an advisory group the first year, provided the AID Mission in Khartoum could fit it into their budget cycle for future funding. Mrs. Bannigan said that NAS/NRC would explore the matter further with the Office of Science and Technology in Washington. Dr. Carpenter said he would see whether future USAID funding would be available.

In-depth discussions were then held with Yahia H. Hamid, Director, Energy Research Institute of the National Council for Research. Dr. Hamid said that the Institute was in the process of completing an energy assessment for the Sudan. However, he felt that the Institute could use assistance in establishing priorities in energy planning. The possibility of a workshop was discussed, which could be scheduled tentatively for later 1979 or early 1980. This would give the Institute sufficient time to publish an energy assessment currently being conducted and make the necessary arrangements for a workshop.

Further discussions with Dr. Carpenter indicated that though he was amenable to the proposed energy planning workshop, there were no USAID funds available for activities in this area. Mrs. Bannigan said that possibilities for alternative funding could be discussed with AID officials in Washington.

The Sudanese officials asked Messrs. Bailey and John E. Gallagher and Dr. Haller if they could extend their visit to observe and comment on present and proposed fish hatchery operations and on herbicide application techniques and problems. Mr. Bailey's Trip Report of February 12, 1979, records his observations and recommendations. Messers. Haller and Gallagher's joint report is currently in preparation.