Aquatic Weed Management: Integrated Control Techniques for the Gezira Irrigation Scheme (1979)

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AQUATIC WEED MANAGEMENT:

INTEGRATED CONTROL TECHNIQUES FOR THE GEZIRA IRRIGATION SCHEME

Report of a Workshop 3 - 6 December 1978

Co-Sponsors:

University of Gezira
Wad Medani, Democratic Republic of the Sudan

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

University of Gezira 1979
Wad Medani, Sudan

PREFACE

This is a summary of a workshop on the management of aquatic weeds in the irrigation canals of the Gezira Scheme, Wad Medani, Sudan. The workshop, held December 3 - 6, 1978, was jointly sponsored by the University of Gezira and the U.S. National Academy of Sciences-National Research Council (NAS/NRC). The broad objective was to formulate recommendations for an integrated weed management program using short- and long-term control techniques.

Irrigation canals are designed to lead water to agricultural lands where required. The efficient flow of water is impossible to maintain when the canals are choked with aquatic weeds. The most obvious reason for controlling these these weeds is to enable the canals to operate at their maximum efficiency.

However, another reason for weed control, often overlooked, is to alter conditions that favor the transmission of disease. Malaria and bilharzia are endemic to the irrigated areas of the Sudan and their control is of prime importance. The irrigation canal water, slow moving, and rich in vegetation, not only supports the vectors of these diseases but also is an ideal environment for their propagation. This added dimension makes it imperative that an integrated, coordinated approach be considered in the design and implementation of present and future programs of aquatic weed control.

This publication is written for administrators and scientists dealing with weed-infested irrigation systems in developing countries. Part A of this report considers the three principal control methods--biological, herbicidal, and mechanical or manual. Bart B contains the workshop papers and background materials and is specific to the Sudan.

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CONTENTS

PART A

SUMMARY REPORT

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 staff of the Board on Science and Technology for International Development (BOSTID) 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, which is situated in Wad Medani, in the center of the Gezira Scheme. Agricultural products derived from gravity-flow irrigation are the economic mainstay of the Sudan, and the Gezira is the oldest and largest system of that kind. Moreover, it is the engineering model for all other irrigation schemes in the Sudan. Wad Medani, approximately 150 kilometers 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 sediment and the slow-moving, often clear water from the Nile, coupled with 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 defined as plants that grow where man does not wish them to grow, and plants growing in the irrigation canals certainly fit this definition. Aquatic weeds are commonly categorized 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 emersed 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. Weed maintenance of the Abu XXs and VIs, 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 serious 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), Managil (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 Naama (85 km). All provide conditions that are advantageous for macrophytic aquatic weed growth because of their construction, design, nutrient rich sediment, and a slow rate of flow that makes them practically stagnant pools. Thus these canals are heavily infested with weeds anchored in the mud.*

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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 emersed weeds such as *Panicum repens* L., *Cyperus rotundus* L., *Ipomoea reptans* Poir, *Cynodon dactylon* (L.) Pers. and *Typha angustata* Bory & Choub.

Such aquatic weeds, interfering with water flow in the minors, have become a serious limitation to the efficiency of the Gezira system of irrigation. Because the canal network provides water to the people for drinking, cooking, bathing, washing clothes, fishing, and watering animals, the control measures must be compatible with the multiple-use factors.

Aquatic weed control is carried out through one, or a combination of, the following methods: biological, herbicidal, 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 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 employed.

Herbicidal 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 the demand for unskilled laborers increased significantly in the urban centers and the neighboring oil-rich states. Also, there was an increasing awareness of health hazards associated with working in the canals and the social status of the work was low. The laborers had other options and exercised them. Thus, the irrigation scheme managers were faced with increased clearing demands and a reduced labor force.

The tendency was to turn to herbicidal control. However, this method requires special techniques, equipment, and trained personnel, as well as foreign exchange for the chemicals. Herbicidal control is further complicated because of the threat of contamination of adjacent food and commercial crops. Care must also be taken to protect the fish, animal, and human populations living in and near the waters being treated. Herbicidal 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 herbicidal applications as well as for other control measures. For the most part, however, this basic knowledge is not yet available, and in fact an inventory of noxious weed species in the Gezira is just being completed (1978-89).

The advantages of herbicidal control are that dramatic results can be achieved within a few days (or less) of treatment and that costs are relatively low. Disadvantages--in addition to environmental concerns--are that large masses of dead plant material may obstruct shallow canals, causing oxygen depletion and leading to eutrophycation and subsequent regrowth of the same or other noxious species. In sum, herbicidal 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 facing increased demands for maintenance and difficulty in recruiting sufficient laborers. The remedies are use of herbicides with short-term efficacy and accompanying disadvantages; mechanical control with expensive equipment and little variety of choice; and promising, yet largely untested and limited, biological control techniques. It was in this context that the Sudanese turned to the NAS/NRC for assistance and cooperation.

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 network and its weed problem. For the final day of the workshop, the participants met in three working groups to discuss biological, herbicidal, 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.

The University of Gezira hosted a reception Saturday evening, December 2. Following the formal sessions and field trip, 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:

<u>Sunday, December 3</u>

A.M.

Chairman: Hamid O. Burham, Director-General
Agricultural Research Corporation

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

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

Refreshments

Paper: The Nile in the Sudan

- M. E. Beshir
  Department of Biological Sciences
  University of Gezira

General Discussion

P.M.

Chairman: David L. Sutton

Paper: Gravity-Flow Irrigation in the Sudan

- Kamal M. Abdu, Director
  Irrigation Services
  Ministry of Irrigation, Wad Medani

Paper: Crop-Water Requirements and Operation of Minor Canals

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

Discussion: Mechanical Control in the United States

- C. M. (Brate) Bryant
  Aquamarine Corporation

- William C. Doering
  Special Products Division
  Lantana Boatyard

General Discussion

Monday, December 4

A.M.

Chairman: M. Bakheit Said, Deputy Director-General
Agricultural Research Corporation

Paper: Distribution of Aquatic Macrophytes in the Gezira

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

Paper: Schistosomiasis in the Gezira

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

Paper: Malaria in Irrigated Agriculture

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

Discussion: Herbicidal Control in the United States

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

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

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

General Discussion

P.M.

Chairman: M. Obeid

Paper: Past and Present Methods of Control

- A. M. Hamdoun

Paper: Biological Control by Fish

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

Paper: The Engineer's Viewpoint

- Kamal M. Abdu

Discussion: Biological Control in the United States

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

General Discussion

Tuesday, December 5

Field Trip: Gezira Irrigation Network

Wednesday, December 6

A.M.

Working Group Discussions

P.M.

Chairman: M. Obeid

Report: Biological Control

Report: Herbicidal Control

Report: Mechanical Control

Report: Summary & Recommendations

Thursday, December 7

A.M.

Departure from Wad Medani

Participants

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Joe Whitney, Institute of Environmental Studies, University of Khartoum, Khartoum

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William M. Bailey, Jr. (Rapporteur)
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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 help in the planning phases of irrigation projects and in deciding upon and implementing techniques for controlling aquatic weeds.

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

3. In order to achieve integrated weed control objectives, a multidisciplinary team should undertake a long-term research project. 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. Intensive research should be carried out on the biology, ecology, taxonomy, and distribution of aquatic plants, and the information applied to improving weed control. 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 <u>not</u> intermediate hosts of schistosomiasis and feed intensely on aquatic vegetation, i.e., <u>Marisa</u> 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.

4. The Ministry of Health, in coordination with the Ministry of Irrigation, the Universities of Gezira and Juba, the Sudan 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 various irrigation systems should always be taken into consideration 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 number 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 Sudan Government, 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 weeds.
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 insecticides to the fields should be improved to limit the amount 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. Biological control agents, in addition to 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. 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 the herbicides recommended should not be detrimental to any aspect of the Gezira or other irrigation schemes. The herbicides recommended have attained the U.S. Environment Protection Agency's standards.

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

4. Research programs in aquatic weed control should be rapidly expanded. Such programs should provide for training of more personnel in weed sciences, 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 Universities of Gezira, Juba, and Khartoum. This pilot project would also include studies of the weed biomass, and monitoring the uptake of herbicides and their fate in the aquatic ecosystems and in the different agricultural crops.

Long-range Herbicidal Research

Some urgent needs in the herbicidal control program have been detailed earlier, including education and the testing of herbicides listed in Table 1. Effective control programs will require continuous modifications, which can only result from continuing research. Agricultural 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 weed control programs.

1. Recommendations in this section 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 emersed plants could be alleviated by adding oil surfactants to the tank mix.

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
Emersed Weeds	mains, majors, near villages	Glyphosate	9 litres/ha	b	Very safe to use on emersed weeds, no herbicidal effect expected in irrigation water.
Emersed Weeds	minors Abu XX	Glyphosate Dalapon Diquat or (paraquat)	see label " " " "	b c 0.1	Foliar sprays usually result in very little herbicide in water. These herbicides should be safe used in close proximity to crops in Abu XX. Drift control and surfactants will be beneficial. Spray dry Abu XXs for maximum safety.

a. Tolerable levels of endothol 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 chemical industry. Current labels of endothol 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 emersed plants will be insignificant.

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

3. Studies using herbicides during canal draw-down as a control technique could also improve weed control programs. Initial tests could be conducted in drainage or experimental 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 herbicidal weed control programs can solve some of the problems. Contamination of water used intensively for agriculture and domestic purposes is an obstacle that can be avoided by careful planning and proper hebicide selection and application. Training of weed control personnel and additional scientists is needed. Herbicidal control projects can be started immediately and a full-scale, effective program can be in operation within a few years if both the authorities and the public recognize the weed problem and dedicate themselves 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.

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 plants. 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 has been found to be 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 *Spirogyra*, and floating plants such as *Lemna* or *Wolffia*. Weeds that have not been controlled by biological means under field conditions include most of the emersed 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, or competitive plants.

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 elevated canals burrowing species, such as crawfish, are an obvious danger and should not be used. Similarly, competitive plants, such as the dwarf spikerush, need to be screened to ascertain whether or not the plants might provide additional 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 can be 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 intensively. If the organism proves effective, then its effects upon nontarget species and the environment must be studied. Production costs must also be considered to determine if this method is practical for field application.

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 biological control agent may be far longer. Therefore, it is more practical at this point to consider the work done elsewhere and then apply this knowledge to the problems in the Gezira. This approach will reduce much of the time and expense involved in developing a biological control method. Experience has shown 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 future populations.

Weeds can be eradicated by the use of herbicides, but many problems are associated with their use. They are only partially effective, their efficacy is generally temporary, and their cost can be very high. They may have unknown effects on the environment, particularly with regard to residue persistence in water, soil, plants, and animals. 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 works gradually 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 emersed weeds such as Typha. Further, grass carp will not reproduce under Sudanese conditions without hormone injections, requiring skilled personnel and special equipment. The requirements for special equipment and trained manpower, however, generally are the same 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 canals containing fish populations. Care must therefore 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 readily fits the needs of 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 grass carp control method.

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

The use of grass carp for weed control 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, about ten per hectare, stocked in canals that do not have plants, may prevent weed growth.
- Grass carp consumes all exposed plant matter, thereby reducing the habitat for disease vectors. The addition of common carp, which uproots plants and consumes bilharzia-carrying snails, might be a further aid. Weed control will also reduce breeding areas for mosquitoes and will enable the mosquito fish 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 *Cyperus* species) on the canal banks and in smaller Abu XXs. The submersed weeds constitute a favorable habitat for bilharzia snails, and the shallow water in the Abu XXs provide excellent habitat for malaria vectors. Further problems caused by these weeds are a serious reduction in water flow. 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 potential economic losses caused by aquatic weeds, particularly studies relating to the reduction in worker productivity due to aquatic-borne diseases and the value of reduced crop yield as a function of reduced water supply to crops.

Generally, weed control methods are divided into three traditional approaches: biological, herbicidal, and mechanical. The herbicide working group stressed the need for an additional approach--prevention. Current weed problems appear to be resulting from indigenous 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 that is spreading rapidly throughout the world. The Ministry of Agriculture has an active program that has successfully prevented water hyacinth from reaching the Gezira. This aspect of weed control should be strengthened by the authorities 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, the use of canal water for domestic purposes, including bathing, drinking, and watering livestock may argue against the use of some herbicides. Consequently, without a major educational program the use of toxic but very efficient herbicides, such as acrolein, may not be 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 where it is applied.
2. Treatments at initial concentrations will be absorbed by plants and adsorbed by the soil. Physicochemical and biological degradation will begin resulting in much lower herbicide levels in the water after 48 hours.
3. Herbicide treatments to non-flowing water generally give better results.

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(s) when the irrigated crops are several centimeters tall.

Emersed plants are easier to control, and fewer potential hazards exist than with herbicide treatment of submersed weeds. Emersed 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 supplies. 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 herbicides recommended have low mammalian toxicity and, so far as is known, will not have adverse effects on irrigated 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 herbicides 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 emersed 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 are essential for the health and safety of the operating personnel, to avoid damage to crops and fish populations, and to protect the health of human and animal populations.

The herbicide working group has recommended the safest herbicides 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 village populations in the Gezira, to fish, wildlife, and animal populations, and to irrigated crops. Proper application and use of the herbicides should result in considerable economic benefits and should not be detrimental to any aspect of life in the Gezira.

The use of herbicides 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, among other factors, by aquatic weeds that retard the flow of water; 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 their 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 drying 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 herbicide 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, crops, 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 and other Schemes. 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 submersed and emersed 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, can pose some problems of interrupted movement 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 canal bank 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.

The two types of control systems mentioned above are envisaged 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 km per day;
- Rate and frequency needed for weed removal;
- Quantity of vegetation removed;
- 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 a sound basis for the choice of a system. It will be advantageous if different schemes can be included in the trial so that the various types of mechanical 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 biological and chemical control methods.

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. The U.S. participants brought films and slides of pertinent weed control activities, extensive literature, and abundant samples of herbicides and application equipment. In addition, three of the U.S. panelists were invited to remain for further consultation after the workshop ended.

Overall attendance at each formal session was 35-40 people, and the quality of background papers and participation was high. Some of the outside participation tended to endorse biological methods--probably in view of the global concern for the environment. Having heard and considered all points of view, 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. M. Obeid, Vice-Chancellor, 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 will be launching a weed research and training program at the graduate level in early 1980. 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. Finally, aquatic weed research has received relatively little attention in the Sudan in the past, (apart from the 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.

PART B

WORKSHOP PAPERS AND BACKGROUND MATERIALS

M. E. Beshir, Editor

INTRODUCTION

M. E. Beshir

The University of Gezira has designated aquatic weed management as a priority need. This focus falls within the educational and research responsibilities outlined in the 1975 Act creating the university.

Irrigation systems are designed to provide water to crops; aquatic weeds in the canals impede this function. Their control, therefore, is necessary for basic agriculture. Aquatic weeds also create conditions favorable for disease vectors. The health problems and their related socioeconomic consequences make control all the more vital.

Aquatic weed infestation in the minor canals is a direct result of the now more-or-less continuous operation of these canals. An environment suitable for weed growth exists year-round because of the intensification and diversification of irrigated agriculture.

Once the aquatic weed problem was defined, the next step was to assess its dimensions and propose solutions. Within this framework the University of Gezira hosted the workshop, with joint cooperation and sponsorship of the U.S. National Academy of Sciences-National Research Council (NAS/NRC).

The workshop consisted of a field trip and discussions between a Sudanese panel, which defined the nature and scope of weed infestation and its associated problems, and an American panel, whose members shared their experience in the study and control of aquatic weeds in various waterways and systems. The recommendations proposed by the joint Sudanese-NAS panelists (Part A of this report) were based on background data, discussions, experience and observations.

This portion of the workshop report includes the background data beginning with a brief synopsis of the history, geology, and hydrology of the Nile. The method of gravity-flow irrigation is described in some detail, including the design and total length of the irrigation networks in the various irrigated agricultural schemes in the Sudan.

One paper discusses the irrigation requirements of the different crops, as established by field measurements, and compares them with the actual releases from the Sennar Dam.

The same paper gives evidence of the "loss of head," which often occurs as a result of continuous operation of minor canals necessary to meet the increased demand for water caused by the policy of intensification and diversification of agriculture. This loss of head results in a further retardation of water movement and helps create additional stagnation of the minor canals.

The distribution of weed species in the minor canals is discussed in three papers. Collectively they provide a provisional checklist of the species present in the canals, their growth patterns, and the manual methods employed for their removal.

Waterborne health hazards (malaria and bilharzia) associated with the canals are outlined by two contributors, who provide data on history, species, and endemicity, as well as indications of the socioeconomic consequences of the two diseases.

The final paper reviews the potential of the Chinese grass carp for controlling aquatic weeds.

This portion brings together the data available to date concerning aquatic weeds in the Gezira Scheme and it is hoped that it will be a useful source book. Although the data are specific to the minor canals in the Gezira, they are believed to be useful and applicable elsewhere because of the similarities of the different irrigation schemes in the Sudan.

I would like to thank the authors for their excellent contributions and for their response, concern, and enthusiasm about aquatic weed management.

My thanks are also due to M. Obeid, Vice-Chancellor of the University of Gezira. Dr. Obeid initiated this endeavor and gave it all his encouragement and support.

The University of Gezira is grateful to the National Academy of Sciences for its support.

THE NILE IN THE SUDAN

M. E. Beshir

In terms of geologic time, the origin of the Nile dates back to the Miocene period and probably farther (25 million-36 million years ago). In a human time scale, the Nile history is also very old. At least in its northern parts, the Nile Valley has been the home of the civilizations spanning some 20,000 years--a history unparalleled in vigor and continuity. This has recently been revealed by radiocarbon determination of paleolithic artifacts from the Nubia.

The Nile as we now know it is young; the existing hydrologic pattern is no older than 12,000 years and may be as young as 10,000 years. At that point the climate along the river changed and moved gradually into a phase of aridity. By the fourth millennium B.C., Egypt and the far northern Sudan began to feel the advent of desert conditions. The savanna that prevailed disappeared and man had to move to be near the permanent water supply--the Nile. Soon afterward, attempts at water management began.

About 5,000 years ago, Menes, the first king of Egypt, dammed the river to build the city of Memphis. Since then, much human effort has gone towards controlling the river upon which life depends, and it was man's influence that turned Egypt and the Sudan green through agriculture irrigated from this great river.

Farther south in the Sudan, interest in the origin of the Nile aroused Herodotus, in about 460 B.C., to undertake his famous journey to the Second Cataract in an endeavor to find the source of the Nile. The Arab penetration into the Sudan, which began in 651 A.D., brought into the country Arab travelers and scholars, among them the famous geographer Idrisi in the 12th century, who wrote what might be the first ecological account of the country with the Nile as its most striking physical feature.

European visitors and explorers began visiting the Sudan in the late 18th century, and with them a new interest in the Nile began. In the first half of the 19th century, antiquities of the Nile civilization captured the most interest, but in the second half of the century the quest began for the source of the Nile.

Geomorphological History

In its present form, the Nile is believed to have begun as several distinct systems that became joined at a late stage in geological history. Each part is related to a different historical and structural development.

The Blue Nile basin was formed as a result of the uplifting of the Ethiopian plateau, which was accompanied by volcanic outpourings. The headwaters of the White Nile drain the tectonically and volcanically active Ugandan plateau. In the Sudan, the White Nile basin occupies a very broad and ill-defined tectonic depression, including the Sudd. The main Nile north of Khartoum is less structurally controlled and flows in the tectonic low behind the Red Sea hills.

The available geological and geomorphological evidence indicates that the Blue Nile is an ancient river system dating from late Cenezoic period when the Afro-Arabian Swell was formed. It flows across its own sediments from Roseries northward. Its valley widens gradually until about the latitude of Sennar, where it merges with the Gezira Plain, and the river is still incised well below the general topographic level.

The White Nile system in Uganda, commonly known as the Albert Nile, is believed to have joined northwards as late as the Pleistocene. North of Nimule, the river is known as Bahr el Jebel and flows over the outcrop of the Umm Ruwaba formation, which is of tertiary and Pleistocene origin and consists of lacustrine and fluviatile sediments. It flows as far north as Mongalla in a well-defined valley. The valley walls decrease in height, until at Bor they merge with the surrounding country and the river enters the Sudd swamps.

In this region there is a marked downstream slope and in clear river channels the flow is very strong, reaching 1.1-1.3 m/sec in the main stream. The swamps are therefore formed not by longitudinal ponding of channels but by overbank floods. The flow of water through the Sudd is controlled by the height of Lake Victoria. The sudden and unusual increase in the lake level in 1964, when it reached its maximum recorded discharge of 36-51 billion m^3, was the cause of the flooding in southern Sudan.

South of Malakal, Bahr El Jebel is joined by the Sobat, which rises in the Ethiopian Highlands. It has a strong seasonal flow similar to that of the Blue Nile. It is thought to have originated in post-Oligocene times.

The White Nile from the Sobat junction to Khartoum is a rather unusual river with a gradient far lower than that of the Sudd, the fall being 11.6 m in 800 km or 1 in 70,000, with a corresponding decrease in current.

North of Khartoum, alluvial deposits are restricted and the main Nile flows to the north over the Basement Complex and Nubian formations. Details of the history of the Nile in the northern Sudan are subject to debate, since evidence is still fragmentary. Current studies are using radiocarbon dating. Further studies will be needed to complete a coherent stratigraphy of the Nile in the northern Sudan.

Hydrology

The Nile, 6,695 km long, is the longest river in the world. Of this length, not less than 3,852 km lie within the borders of the Sudan A further 800 km can be added for the Blue Nile and about 2,250 km for the tributaries of the White Nile. Adding this to the intermittent rivers such as the Dinder, Rahad, and Atbara, some 7,000 km of rivers are within the Sudan.

The average annual flow of the Nile measured at Aswan is 86 billion m^3 with great variation both within and between seasons. More than 80 percent of the annual flow occurs between August and October, while the remaining 20 percent is discharged over the other 9 months of the year. The year-to-year variation is also great; the maximum recorded discharge was 155 billion m^3 in 1878 and the lowest recorded was 42 billion m^3 in 1913.

Waters draining from the Ethiopian plateau (Blue Nile, Rahad, Dinder and Atbara) account for 86 percent of the total annual flow. Only 14 percent comes from the equatorial reaches of the Nile, with the low contribution due to the losses (10 billion m^3) that occur in the *Sudd* area through spillage and evaporation.

Irrigated Agriculture

Of the Sudan's total area of 2,496,138 km^2, 49 percent is desert and semidesert, with a rainfall of not more than 300 mm/year. Twenty-seven percent is savanna, with rainfall between 300-800 mm and only 24 percent is tropical forest and wetland savanna.

Annual rainfall is low and seasonal in character. The Sudan is consequently very dependent on the Nile systems for perennial irrigation for reliable agricultural production. The flow level of the Nile is also seasonal, with some of its tributaries running only part of the year. It is therefore necessary to regulate river flows by dams and irrigation networks.

At present 4.68 million feddans are irrigated, comprising the Gezira, New Halfa, Rahad, Suki, Tambul-Gunied, West Sennar, Abu Naama, Assalaya, Kenana, and the Agricultural Reform Schemes. These schemes now use 18,258 billion m^3 of water. Sudan's share of the Nile's waters is 20 billion m^3.

Aquatic Habitats

The vegetation of the Sudan is classified into five zones, one of which is the aquatic habitat of the Sudd, which comprises an area of approximately 95,000 km^2 and is perhaps the largest swamp region in the world. The other vegetation zones are adapted to the highly seasonal rainfall conditions.

Apart from the Sudd, the Nile system offers the only other potential environment for aquatic or semiaquatic plant life. With the introduction of irrigation in the arid climate of the northern Sudan, new aquatic habitats have been created. The extent of these habitats is increasing as irrigated agricultural development continues. At present, irrigation networks, including main and branch canals and drains, total some 18,000 km.

A STATEMENT OF THE PROBLEM

M. E. Beshir

In the past decade there has been an increase and proliferation of aquatic plants in the minor canals of the Gezira Scheme. This has been a direct result of the new policy of intensification and diversification of the cropping patterns.

Formerly, only 63 percent of the land was under cultivation at any one time because Sudan's share of the Nile waters was limited. After the 1959 Nile Water Agreement with Egypt, Sudan's share was increased, permitting implementation of the intensification program in 1961.

The immediate outcome of intensified cropping was an increased demand for irrigation water, with the consequence that minor canals became operative throughout the year. Prior to 1961 many of the minor canals were shut off after the end of March. This closing resulted in a drying period of up to three months which, coupled with the high temperatures during March to June, afforded a reasonable degree of weed control through desiccation and growth retardation. The present situation is that of continuous water flow in the canals, and since the flow velocity is normally low, conditions of ponding conducive to weed growth have been increasingly created. The extent of the problem of weed growth in the canals can best be appreciated when one knows there are some 7,200 km of minor canals in the Gezira Scheme. Ponding conditions are the result of the topography and canal design.

Most of the weed species are of the submersed type with the greatest rate of growth occurring after November when the sediment carried in the flood waters has been deposited, which allows greater penetration of light. In turbid, sediment laden flood waters, light penetration is reduced and the growth rate of most species is retarded. Fruiting and seed setting occurs during the period of clear water, although some seed germination occurs in turbid waters.

These growth characteristics have been the basis for the normal control method using saw-like chains. The clearing or cutting is applied on a regular schedule; during the period of clear water the vegetation is cut every 10-15 days and is designed to weaken vegetative growth. A longer periof (20-25 days) is allowed between cuttings during the turbid water period.

This method proved very successful in the past mainly because of the availability of labor at cheap prices. However, with the development of additional irrigated land in the Gezira and elsewhere, escalating labor costs, and health hazards, the present method leaves much to be desired in terms of economics, effectiveness, and feasibility.

It is to be noted that the minor canals in the Gezira and elsewhere are aquatic habitats in the arid climate of central Sudan. The only natural aquatic habitats in the Sudan are found in the River Nile and its tributaries and in the swamps of the Sudd region. The canals are man-made aquatic habitats, and their extent and potential for aquatic weed habitation increase with every irrigated agricultural development project. Therefore, new and innovative weed control techniques are needed to respond to the present situation.

OPENING ADDRESS

David L. Sutton

It is indeed a pleasure to be able to attend this workshop and share with you some of the aquatic weed control technologies that are currently being used and developed in the United States. Adequate supplies of fresh water are essential to the well-being and economic health of any country. Location of population centers and farming activities are highly dependent on the availability of water from rainfall and on the ease with which water can be moved from one location to another.

I have always been interested in the Nile because of the close association of man to its natural cyclic flow and its place in history. It has been a great personal pleasure for me to be able to see this great river and better understand its influence on the history and development of the countries through which it flows.

Based on estimates for population growth in the coming years, it has been estimated that the world's population will double in the next 25 to 35 years. The impact that this increase will have on present resources is difficult to comprehend. Another way of looking at it is to view the progress of crop production. The world's present crop production is based on knowledge which has been gained since man first planted crops and harvested their yields. The increase in crop production in the next 25 to 35 years must equal the total yield since the beginning of agricultural production.

It appears that the amount of cultivated land throughout the world in general will not increase substantially. However, there are a few countries, such as the Sudan, which offer the hope of being able to add to the land area available for crop production.

One of the greatest challenges for the remainder of this century will be to double our present-day crop production figures. The Sudan appears to be one of the few countries that has the land and resources to become one of the major centers for crop production to meet the needs of the world's expanding population. It is my hope that our participation in this workshop will in some way assist you to make wise choices and decisions about the technologies that will lead to a higher level of crop production in your country. During these next few days, I hope that our discussions will stimulate ideas on the formulation of short-term as well as long-term strategies for helping to manage aquatic weed problems.

Aquatic macrophytes are an integral part of all freshwater systems. In the evolutionary development of plants, only a few of the myriad of plants have been able to adapt to the harsh climatic conditions created by an aquatic site. It is estimated that less than 1 percent of all plants can complete their life cycle in or near water. Of these plants, only a handful grow in such profusion as to be classified as weeds or harmful plant pests. The floating water hyacinth (Eichhornia crassipes (Mart.) Solms.) is a good example of an aquatic plant which is classified as a weed throughout the world. We must recognize that some desirable plants, when given the proper set of environmental conditions, can grow in abundance and create problems as great as those from any weed species.

In the recently published book by Holm, et al., On the World's Worst Weeds: Distribution and Biology, water hyacinth is listed as the eighth most troublesome plant pest in the world. This is no news to you who have witnessed the rapid spread and growth of this plant in the Nile's system during the last 20 years. The manner in which this plant is able to invade and dominate an area is not completely understood. A better understanding of the factors affecting the growth of water hyacinth will aid in attempts to control this weed.

In the United States we have recently witnessed the spread and development of another plant, in this case a submersed one, hydrilla (Hydrilla verticillata Royle). This plant can dominate a body of water, crowding out other plants and animals. In canal and flowing water systems, it is proving particularly difficult to control. Again, a better understanding of the life cycle of hydrilla will aid in the search for better methods to manage this weed. We must pay particular attention to any weak spot in its growth and development which will allow for an increase in the effectiveness of a particular control method.

Aquatic weed control methods can be separated into separate and distinct categories. It appears, however, that a combination of these individual methods will be necessary to maximize their effectiveness. Again, a better understanding of the life cycle of the problem weeds will aid in synchronization of these various methods for the most efficient and effective control possible.

This workshop is a contiuation of the dialogue which has been established between the National Council for Research in the Sudan and the U.S. National Academy of Sciences.

I am sure that our presentations will touch on topics which have already been discussed at the previous workshop. Progress toward achieving the goals and recommendations of the previous workshop will be of particular importance in our discussions at this workshop.

There are no easy answers or solutions to the problem of controlling aquatic weeds. If there were, then we would not be here to discuss the problems that exist in the Nile and in many aquatic sites in the United States. I hope that our discussions at this workshop will increase our understanding of the causes of the aquatic weed problem in addition to giving us a better understanding of those methods and techniques which have produced results in some situations and enabling us to apply them to other weed areas.

On the one hand, we know that aquatic plants will grow in a body of water and are essential to the overall productivity of that system. On the other hand, when plant growth disrupts the productivity in that site or interferes with water use, some attempt must be made to manage the plants so that they can both be of benefit to the natural productivity of the water and allow for effective use of the water for man's activities.

I think that the concept we should strive for is a management system which allows for growth of aquatic plants but holds their growth to an acceptable level. The species of aquatic weeds and sites determine to some extent the methods which can be used. For example, only certain herbicides can be used for weed problems in potable water supplies.

Another concept which has attracted considerable interest in recent years is the utilization of aquatic weeds. Several approaches, such as their use as feedstocks and in composting, appear promising. In any management program, effective use of excessive weed growth would help to offset the control costs. However, this use must be cost-effective and produce a product which will be of benefit or serve a useful purpose.

In the United States, management programs are using primarily herbicidal, mechanical, and biological methods to control aquatic weeds. I would like to briefly discuss some of these and to summarize some of our attempts to control various aquatic weeds in different sites.

As I mentioned earlier, hydrilla has become a major weed problem in the United States. This plant was first introduced in Florida in the late 1950s and since that time has spread to a number of states, but is causing the biggest problem in Florida. This plant has proven to be extremely difficult to control. It is estimated that hydrilla is present as a severe infestation in approximately 81,000 hectares in Florida and occurs to a lesser extent in another 202,000 hectares.

No natural enemies have been found in the United States to check the spread of hydrilla. Although the plant is found primarily in tropical areas, it has the ability to grow under temperate conditions as well.

Herbicides are one of the most cost-effective means of controlling many aquatic weeds. However, environmental concern over use of these chemicals in the water and rising developmental costs have tended to reduce the introduction of new herbicides in recent years.

Most improvements in herbicide technology have been made in herbicide formulations or application techniques. The mixing of herbicides with oil and water and an emulsifier to form an emulsion is one method of placing the herbicide in close contact with the target weed species. Depending on the solubility of the herbicide, it is mixed with the oil or water prior to the forming of the emulsion. A weighting agent is mixed with the emulsion to increase its specific gravity for use in controlling sumbersed weeds. The emulsion is injected underwater and sinks toward the bottom until it comes in contact with the weeds.

Another recent development in herbicide technology is the mixing of certain herbicides to produce synergistic effects. In other words, the phytotoxicity of the resulting mixture is greater than that of the individual compounds. In this way, less herbicide is required to control the weeds.

As you know, biological control methods involve the use of one or more organisms to feed on the weeds and reduce their biomass until they are no longer a nuisance. One of the problems with the introduction of a biological control method is to ensure that the organism being introduced does not become a pest more serious than the one which it has been introduced to control. Host specificity or some other control measure of the introduced organism is essential so that it does not become a problem.

The best example of biological control of an aquatic weed in the United States is the use of the alligator weed flea beetle to control alligator weed. This flea beetle has been quite effective in reducing the extent of alligator weed in areas in Georgia and north Florida. The flea beetle is not as effective in other areas, apparently because of temperature and predators.

The most recent development in biological control technology involves a controversial herbivorous fish, the grass carp (Clenopharyngodou idella Val.). The grass carp (also commonly called the white amur), although not as host specific as the alligator weed flea beetle, appears to have great potential for the control of a number of aquatic weeds, particular submersed ones. The grass carp does not reproduce in static water; therefore, its number can be controlled through stocking of fish in these areas. The spawning requirements of the fish are somewhat restrictive in that a river system or flowing water is required for natural reproduction. Natural spawning in static water has not been reported, although the fish has spawned in several areas outside its native habitat. Its native spawning areas are the large river systems of eastern China and Siberia, within a latitude of 50 to 23 degrees. As mentioned, the grass carp has been introduced into a number of countries but has spawned naturally in only a few river systems in Mexico, Japan and the western part of the Soviet Union. It is present in the Mississippi River system in the United States, but apparently has not spawned yet. The grass carp is a member of the cyprinid family, but is readily distinguished from other fishes in this family by its double-rowed and comb-like pharyngeal teeth. These teeth are well adapted to tearing and lacerating plant material by the movement of one set of teeth against the other and against a hard pad located on the roof of the pharnyx.

The young grass carp subsists on a diet of algae, rotifers, and other microorganisms. As it increases in size, the amount of animal material it eats decreases and the proportion of aquatic vegetation increases, until its diet is almost exclusively vegetation. The grass carp can grow at a rate of one kilogram or more per month, depending on the abundance of vegetation and on water temperature.

An additional benefit of using the grass carp is that part of the weeds are converted to fish protein. In many areas, the grass carp is being cultured as a good fish for human consumption.

Mechanical methods are useful in areas where herbicides or other methods are either ineffective or restricted. Mechanical methods may be particularly useful for opening up areas such as boat trails or channels in canals. Utilization of the removed weeds will help offset the costs of mechanical control methods.

Control of weeds in flowing water and in potable water supplies are the two most difficult areas of water plant management in the United States. The use of several combined methods may be necessary to control weeds in these areas. As mentioned earlier, it is the aim of aquatic weed control to manage or to reduce the plant growth to an acceptable level. In many cases, when one weed is removed it is replaced by another plant or by regrowth of the weed itself. Most of the control methods are only temporary, and the weeds quickly regrow or are replaced by other noxious plants. No one control method appears to be ideally suited for every weed problem. Rather, it appears that an effective control program will make use of all of the methods to keep the weeds to an acceptable level.

It is my hope that at this workshop we can investigate the reasons that various methods work in certain areas and don't work in others, and that information gained from our discussions will be useful in formulating weed control measures for your canal systems.

Again, I appreciate this opportunity to be able to discuss with you the various technologies for use in the control of aquatic weeds. I hope that our participation in this workshop will be helpful to you in controlling aquatic weeds in the Gezira.

Thank you very much.

GRAVITY-FLOW IRRIGATION IN SUDAN

Kamal Mohammed Abdu

The distribution of the annual rainfall in the Sudan ranges from over 1,500 mm in the extreme south to less than 50 mm in the north. In the central and northern parts of the country rainfall is not sufficient for modern agriculture. For this reason, people in these areas have depended mainly on the Nile and its tributaries for centuries.

There are several different irrigation methods practiced in the Sudan: gravity flow, pumps, basin, and flush irrigation. However, gravity flow is the major method.

Gravity Irrigation Schemes

In these schemes, water is taken from the upstream side of a dam and flows by gravity to the crop fields. The main irrigation schemes are:

- Gezira and Managil Extension Schemes taken from Sennar Dam on the Blue Nile with an area of 2,150,000 feddans;*
- Khashm El Girba Scheme, taken from Khashm El Girba Dam on Atbara River, with an area equal to 460,000 feddans; and
- Rahad Scheme, irrigated by pumps on the Blue Nile taken through Rahad Barrage on Rahad River, with an area equal to 300,000 feddans.

Types of Irrigation and Drainage Canals

All irrigation and drainage canals are earth canals, i.e., unlined with a bed slope from 2 to 10 cm/km, and hence the water velocity ranges between 0.2 and 1.0 m/sec.

1. Irrigation canals

The irrigation system generally leads from the dams or reservoirs to main canals, branch canals, major canals, minor canals, and field canals (see Appendicies 1 and 2).

*Feddan = 1.038 acres.

2. Drainage canals

In the main irrigation schemes of the Sudan, the water table is generally 10 meters below the surface. Therefore, drainage canals are required only for surface runoff during heavy rains and are discharged into the Nile. There are three types: minor, collector, and protective drains.

The Gezira Irrigation Scheme

The Gezira is the land lying between the White Nile and the Blue Nile, with an area of over 6 million feddans.

Irrigation started in the Gezira Scheme in 1911 as a small experiment for growing cotton, with water pumped from the Blue Nile. After the experiment was successful, the construction of Sennar Dam was started in 1914 and completed in 1925. Initially 300,000 feddans were irrigated. This was the beginning of gravity irrigation in the Sudan.

The irrigated area was increased to 670,000 feddans in 1931, 840,000 feddans in 1937, and was expanded to one million feddans developed by the end of 1952. After independence in 1956, development of Managil Extension began. It was completed in 1968, and added an additional area of almost one million feddans bringing the total to nearly two million feddans. With the development of Guneid and northwest Sennar pump schemes and small fringe areas, the Gezira Scheme reached its present total area of 2,287,500 feddans.

The Ministry of Irrigation is responsible for the planning, design, construction, and water control of all irrigated areas in the Sudan. This includes the operation and upkeep of the Gezira Scheme, although the Sudan Gezira Board is responsible for agricultural management. From the irrigation side, the scheme is divided into six Divisions, which are subdivided into 23 Subdivisions, each under the control of an Assistant Divisional Engineer. The Subdivisions are further divided into Field Sections, controlled by Assistant Engineers.

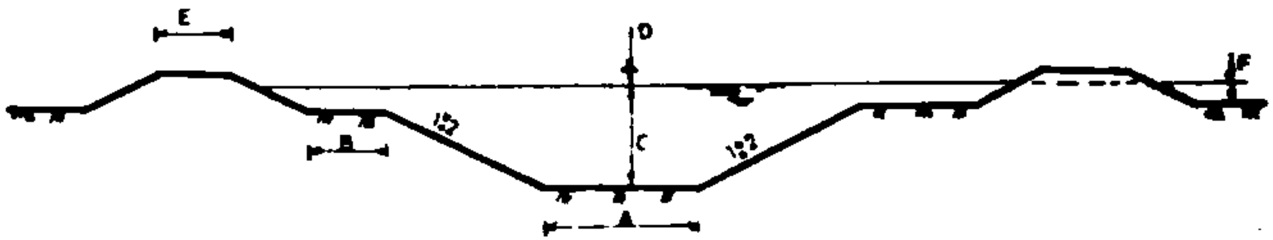
The Agricultural Management divides the scheme into 14 Groups, which are subdivided into 197 Blocks, each under the supervision of a Block Inspector.

The main tasks carried out by the Ministry of Irrigation engineering staff are:

1. Supervision and control of the water supply in canals to ensure that it satisfies the crop requirements;
2. Study of distribution factors and water requirements for different crops in different localities;
3. Study of technical irrigation problems arising in the field and find their best solutions;
4. Clearance of silt and aquatic weeds in the canals; and

5. Annual inspection and maintenance of the water control structures.

APPENDIX 1 Typical Canal Data



TYPE OF CANAL	DIMENSIONS IN METERS						SLOPE CM/KM	LENGTH (1) KM
	A	B	C	D	E	F		
Main	20 - 40	>2.00	2.50 - 4.50	>1.00	>5.00	>2.00	±6.5	632
Branch	10 - 20	2.00	2 - 3.50	1.00	5.00	2.00	7 - 10	860
Major	5 - 10	1.50	1.50 - 3.00	0.75	2-4	0.50	4 - 8	1,852
Minor	4 - 8	<0.50	0.75 - 2.00	0.4 - 0.6	1.00	0.20 - 0.5	2 - 5	11,303
Field	0.5 - 1	0	0.65 - 0.75	0.25 - 0.5	0.50	0.15 - 0.25	0 - 4	±75,000

(1) Length of all irrigation canals in the Sudan up to August 1976.

APPENDIX 2 Lengths of Canals and Drains in Existing Schemes

No.	Scheme	Main Canals Km.	Branch Canals Km.	Major Canals Km.	Minor Canals Km.	Escape Drains Km.	Collector Drains Km.	Total Km.
1.	Gezira	204	136	851	3,856	32	1,108	6,187
2.	Managil	57	452	759	3,958	123	1,138	6,487
3.	Khashm El Girba	27	245	110	1,331	86	515	2,314
4.	Suki	45	-	68	311	-	371	795
5.	Tamboul	-	27	42	304	91.4	50	514.4
6.	Sennar Sugar	57.6	-	22.5	117.9	16.5	51.6	266.1
7.	Abu Na'ama	17	-	-	85.6	-	105.9	208.5
8.	Sayial	28	-	-	25.8	-	27.1	80.9
9.	Kali and Kitayab	22.7	-	-	26.1	-	31.5	80.3
10.	Gammouiya	2	-	-	-	-	-	2
11.	Agrarian Production Schemes	174	-	-	1,288	-	-	1,462
	TOTAL	634.3	860	1,852.2	11,303.4	348.9	3,398.1	18,397.2

CROP WATER REQUIREMENTS AND MANAGEMENT OF MINOR CANALS IN THE GEZIRA

Osman A. A. Fadl

and

Hussien S. Adam

During the 1977-78 season, more than 6 billion m^3 of water were released from Sennar Dam to meet the demand of 1.6 million feddans of various crops in the Gezira. That quantity was carried through canals which were originally designed to meet a cropping intensity of 50 percent of their capacity, but which now operate at 76 percent. It was possible to attain that increase both because of the safety margin in the design and construction of these canals and by enlarging the main canal. Today the canals have reached their carrying limits, and unless their operation and management from the dam to the field are run smoothly, problems will affect all aspects of flow and consequently of crop yields. Obviously, silting and weed growth in canals are impediments to flow, and unless these problems are looked at in proper perspective, efforts to rectify the situation may be unsuccessful.

This paper attempts to discuss the relationship between water flow and weeds in minors and continuously flowing Abu XXs. It includes an account of the water requirements of some crops in the Gezira and the relationship of this with the weather elements obtained, by the use of Penman (E_o) and crop factors. Basic facts related to minors and Abu XXs are presented in connection with aquatic weed growth. The valuable contribution of H. G. Farbrother (FAO-TCP) in field surveys and the data published in his reports and in the Technical Notes of the Gezira Research Station were of great help in preparing this paper.

Climatic Conditions in the Gezira

The average values of the main meteorological elements for Wad Medani are given in Table 1. There are three distinct seasons: a short rainy season (July - September), during which the temperature is moderate and the humidity is high, a cool, dry winter season (November - February), and a hot summer season (April - June). March and October are transitional months.

Wad Medani is in central Gezira. There is a variation of climatic conditions across the Gezira from north to south. The rainfall in the extreme north of the Gezira is 28 percent lower than that of Wad Medani, while the extreme south of the Gezira has a rainfall 27 percent higher than Wad Medani.

During the dry period, the relative humidity does not change significantly across the Gezira, but during the rainy season northern Gezira is drier than Wad Medani by about 10 percent. Southern Gezira has a relative humidity similar to Wad Medani.

Compared to Wad Medani, northern Gezira is about 1°C cooler during winter and 1°C warmer during the rainy season; southern Gezira is about 1°C warmer during winter and 1°C cooler during the rainy season.

Crop Water Requirements

Table 2 shows the monthly water requirements of cotton, groundnuts, wheat, and vegetables in millimeters and in m^3 per feddan. These values are derived from the evaporation data shown in Table 1. The method used is that established by Farbrother.

Farbrother measured actual water loss from different crops over several seasons. Water loss represents evapotranspiration (ET), since the Gezira soil is of low permeability and the water table is 15 m.

ET was calculated from the depletion of soil moisture measured by using the traditional gravimetic methods. Fadl used the neutron probe for these measurements. By comparing ET of the different crops with the evaporation calculated using the Penman formula, crop factors were established. The crop factor depends on the stage of development of the crop. At planting the crop factor is about 0.5, and it increases to more than 1.0 at full development.

The monthly water requirements for the Gezira Scheme can be calculated by multiplying the values in Table 2 for each crop by the area of that crop and then adding the figure for all crops.

Using the above method, the total water required for the Gezira Scheme was calculated for a number of seasons. These values compare well with total releases from Sennar Dam. Table 3 shows the close agreement between the calculated water requirements and the releases from Sennar Dam for the season 1975-76.

Canals and Aquatic Weeds

The operation and control of the main canal, branches, and major canals are the responsibilities of the Ministry of Irrigation. However, minor canals are operated by the Block Inspectors (BI), who are helped by one to three ghaffirs (water guards) and one head ghaffir. A BI calculates daily indents from the number of Field Outlet Pipes (FOPs) to be opened at a Pipe Factor of 5,000 m^3 per day. However, Farbrother surveyed 203 FOPs and found a mean discharge rate of 2,800 m^3 per day. For the judicial distribution of water in the Abu XXs, ghaffirs control the levels in a minor by the number of open FOPs and the size of the opening of gates of the various regulators.

Since the implementation of the policy of intensification and diversification in the 1960s, the number of open FOPs has increased. Therefore, a loss of head (driving force of water) on the FOPs has occurred. It has led some investigators to question the validity of the night storage practice under the new circumstances. Farbrother claims that the unofficial adoption of continuous flow and the abandonment of night storage are major reasons that water supplies have not met the demands necessary for intensification to be successful. It is true, however, that gates are not closed at night, though they are maintained at openings judged to give fair distribution of water. Excessive changes in settings cause abrupt changes in levels, which compel ghaffirs to further change gate settings. It is also a fact that FOPs opening to cotton fields are not closed at night, though their valves might be set to what the tenants consider to be a safe overnight flow.

This continuous flow results in a loss of head and a corresponding decrease in velocity. This, in turn, causes both silting-up and enhanced aquatic weed growth. The scouring velocity at the mouth of FOPs generally prevents such problems in the immediate vicinity of the pipes, but with reduced velocity towards the tail of minors, weed growth on these reaches is often extensive. The degree of growth obviously depends on flow conditions over a period of time.

Weeds increase the roughness of the channels, which causes major losses of head due to friction. Dredging increases the roughness of canal sides causing greater resistance to flow and, thereby, adding to increased silting-out and weed growth.

TABLE 1 Average Values of Some Meteorological Elements (1941-1975) for Wad Medani

	Max. Temp C°	Min. Temp. C°	Highest Max. C°	Lowest Min. C°	Relative Humidity %	Wind Speed m/s	No. of rainy days	Rainfall mm/month	Penman Evaporation mm/month
JAN.	33.4	14.0	40.7	5.2	38	3.6	-	-	174
FEB.	35.1	15.2	43.5	3.3	29	4.0	-	-	192
MARCH	38.3	18.3	44.6	7.3	22	3.6	-	-	236
APRIL	40.8	21.2	46.1	12.0	18	3.1	-	-	258
MAY	41.4	24.0	46.2	15.6	30	3.6	3	15	279
JUNE	39.6	24.7	45.3	16.7	48	4.5	5	27	288
JULY	35.8	22.8	43.6	18.5	68	4.5	11	110	245
AUG.	33.4	22.0	41.0	18.8	79	4.0	12	131	202
SEPT.	35.2	21.8	40.7	17.0	72	3.1	6	52	207
OCT.	37.8	21.6	41.2	13.8	52	2.2	4	17	202
NOV.	36.4	18.0	40.7	8.7	37	3.1	-	-	180
DEC.	33.6	14.5	39.6	4.8	40	4.0	-	-	167
YEAR	36.7	19.9	46.2	3.3	44	3.6	41	352	2,360

TABLE 2 Monthly Water Requirements of Some Crops per Feddan (in mm and in m^3)

		June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Total
Cotton	mm		(P.W) 48	116	141	212	211	185	159	144	103	1,319
	M^3		200	438	593	891	888	775	668	605	434	5,540
G/Nuts	mm	(P.W.) 143	142	181	225	179	79	-	-	-	-	949
	M^3	600	595	760	945	750	330	-	-	-	-	3,980
Wheat	mm	-	-	-	-	(P.W) 143	151	190	104	-	-	588
	M^3	-	-	-	-	600	635	800	435	-	-	2,470
Vegetables	mm	-	-	-	-	203	179	166	174	192	236	1,150
	M^3	-	-	-	-	852	750	698	729	805	992	4,830

P.W. = Planting Water.

TABLE 3 Calculated Water Requirements and Releases from Sennar Dam (1975-1976) (in million m^3)

	June - July	August - September	October - November	December - January	February - March
Releases from Sennar Dam	1,159	621	1,798	1,421	952
Calculated Requirements	1,300	517	1,942	1,546	964

After H. S. Adam and H. G. Farbrother (1977), World Water Conference, Argentina. (Also appearing as technical note No. 12, G.R.S., Wad Medani.)

APPENDIX 1 Data from Minor Canals, Abu XXs and Abu VIs

Minor Canal

1. Gross Factors (GF) of canals: the main canal is constructed on a GF of 14 (i.e., 28 m^3/fed/day at 50 percent cropping). The minor's GF is 17 (34 m^3/fed/day at 50 percent cropping).

2. Minors generally run along the contour lines, 1.42 km apart and of variable lengths, depending on the air irrigated (300 to 13,000 fed).

3. Minors are designed to command 20 cm above the highest spot in the field (up to 50 cm above ground adjacent to banks). This is known as FSL (Full Supply Level).

4. Banks are built 60 cm above FSL.

5. Regulators are constructed along minors to drop the command from 50 cm to 20 cm in the area served by the following reach. The size of regulation pipes decrease in proportion to the area served downstream.

6. Minors were planned to have the gates of the regulators and the FOPs (Field Outlet Pipes) closed at sunset. The discharge continues at the same rate and builds to a level known as NSL (Night Storage Level) by sunrise.

$$NSL = FSL + 20 \text{ cm.}$$

7. Capacity of a minor is maintained along the length of the canal, though the discharges decrease from one reach to another with a consequent reduction of velocities towards the fall.

8. NMS (Normal Maximum Supply) = $\frac{14}{17}$ of the maximum designed capacity (see para. 1, above).

Abu XX

9. An Abu XX is fed from the minor through a (35 cm diam., 12 m long) steel pipe known as an FOB, which is controlled by a valve.

10. The command of an Abu XX is 10 - 20 cm, with banks 50 cm above ground level.

11. The length of an Abu XX is 1.394 km and the distance between channels is 292 m.

12. The channel serves 90 feddans (known as a Number) of the same crop(s) in the rotation.

13. The head on an FOP is the level difference between the appropriate reach and the Abu XX.

Abu VI

14. This channel is spaced at 150 m along Abu XX from which it is fed.

15. The width is 0.6 m and the depth 0.3 m, with the command designed at 8 - 12 cm.

16. The original design was to carry 2000 m3 per 12 hr day.

AQUATIC WEEDS IN IRRIGATION SCHEMES--THE ENGINEER'S VIEWPOINT

Kamal Mohammed Abdu

The Present Situation

The main problem in irrigation canals is caused by aquatic weeds. During the growing season weeds may completely choke the canals, and this creates considerable disturbance to movement of irrigation and drainage water. This problem exists mainly in the field canals (Abus) and minor canals, with weeds causing less trouble in the major canals and very little in the branch and main canals. This is because of the rather high current velocity in the branch and main canals.

In the drainage canals the problem is temporary, since these canals are usually free of water.

Types of Weeds

Two types of weeds can be distinguished in the canals: emersed and submersed.

Emersed and canal bank weeds grow optimally in the rainy season (June - September), while submersed weeds show optimal growth in the winter months (November - February).

During the crop-growing season, all aquatic weeds grow very fast, recovering within about 2 weeks after removal. Water hyacinth has been kept out of irrigation schemes by very strict supervision of all probable points of entry in the neighborhood of the Blue Nile.

In the first 10 years after excavation of the canals, the emersed weeds like Typha predominate; thereafter, submersed weeds become the principal types.

Methods of Fighting Aquatic Weeds in the Sudan

Aquatic weeds are still being removed largely by manual methods. A saw-like chain, which cuts both emersed and submersed weeds, is pulled across the canal by two men. The cut weeds are set on the banks but the efficiency of removing weeds in this way is rather low, and many weeds remain in the canals.

The cost of removing weeds manually is approximately 30 Sudanese pounds per kilometer (about US$75).

Fighting weeds in this way is difficult because:

1. The water is infected with bilharzia;
2. In winter, the water temperature is too low for people to work in the canals; and
3. Too few people are available for removing weeds manually.

Manual weed control is carried out continuously during the year. During the crop growing season, when canals operate continuously, weekly maintenance of the canals is required.

At the end of the growing season (April - May), most of the minor canals are then free of water and both weeds and silt are removed manually. Some years ago the non-irrigation period lasted approximately 4 months, but because of the intensification of agriculture, this period of drying has been reduced to 2 months. This limits the opportunity for weed control in minor canals when they are dry.

Chemical weed control has not been considered seriously because humans as well as animals use these canals to swim, wash, and sometimes for drinking water.

In the Sudan, people are not satisfied with the present ways of weed control; however, other ways to fight aquatic weeds have not yet been used.

New methods of weed control are still in the experimental stage, or, like mechanical weed control, have not yet been introduced. Biological and chemical methods will require years of adaptation and testing in local conditions before there can be a realistic test of their effectiveness.

A PRELIMINARY SURVEY OF AQUATIC WEEDS IN THE GEZIRA CANALIZATION SYSTEM

A. M. Hamdoun

and

L. A. Dissougi

Gravity flow irrigation is an outstanding feature of the Gezira Scheme. Water from the Sennar reservoir continuously supplies the main and major canals which, in turn, feed a network of minor canals. The total length of the minors is about 7,800 km. Minors convey water to Abu XXs, each commanding 90 feddans of cropland. Each Abu XX feeds nine Abu IVs, each irrigating a 10-feddan plot. In addition to supply and distribution canals, the scheme is characterized by a network of drainage channels that take excess water from the fields to the river.

The construction of reservoirs and canalization systems with a slow rate of flow is always conducive to aquatic weed growth and weeds started to appear only 4 years after gravity irrigation started to operate. A gradual build-up took place, and with the recent intensification and diversification of cropping, aquatic weeds are a serious problem.

A study of aquatic plants and their control in the canals of the Gezira was conducted in the 1940s, but since that time no intensive surveys have been made. The purpose of this paper is to present some preliminary results of an on-going survey undertaken to determine the extent of the problem and the common aquatic weed species in the system. The survey was started in November 1978 because weed growth is usually at its maximum and water turbidity is at a minimum.

Methods

Fifty-two minor canals, some Abu XXs, and some drains were selected at random in the South, Center, Messelemia and Wad Haboub administrative groups. In each canal or drain, from 6-9 sections (100-200 m long) were examined. The status of weed infestation, the individual species, and the relative abundance were recorded.

Results

Surveys of aquatic weed growth in the minor canals have so far revealed the presence of three categories of weeds, namely, submersed, emersed, and floating. The species involved are:

1. Submersed
   - *Potamogeton perfoliatus* L.
   - *P. nodosus* Poir.
   - *Potamogeton* spp. (unidentified)
   - *Najas pectinata* (Parl.) Magnus
   - *Ottelia alismoides* (L.) Pers.
   - *O. ulvifolia* (Planch.) Walp.
2. Emersed
   - *Echinochloa stagnina* (Retz.) Beauv.
   - *Phyla nodiflora* (L.) Greene
   - *Ipomoea aquatica* Forsk.
   - *Cyperus rotundus* L.
   - *Cynodon dactylon* (L.) Pers.
   - *Typha angustata* Bory & Chaub.
   - *Polygonum glabrum* Willd.
   - *Phragmites mauritianus* Kunth
3. Floating
   - *Spirodela decima* (Muell.) Ktz.
   - *Lemna minor* L.

Potamogeton spp. and *E. stagnina* are the most common species in minors and are responsible for most of the damage. Of the 52 canals surveyed 60 percent were almost free of weeds because of a recent manual or mechanical control operation, 15 percent were moderately infested, and the rest were heavily colonized. The tail sections of canals are usually clogged by weeds because the water there is almost always stagnant. The main factors governing the degree of infestation are control operations and the amount of time that has lapsed since the last control efforts. Weed growth in a canal is usually not uniform; some sections are clean while others are weedy, which indicates that clearance operations at any one time are not made throughout the length of the canal.

Recolonization of clean minors begins with emersed weeds such as *E. stagnina*, *I. aquatica* and *P. nodiflora*. These species spread from the banks to the water. This could be due to the ineffectiveness of mechanical desilting and of manual pulling or raking of weed species rooted at the banks. The growth of emersed weeds decreases the flow velocity and provides favorable conditions for reinfestation by submersed weeds such as *Potamogeton* spp., *N*. *pectinata* and *Ottelia* spp.

Generally speaking, most Abu XXs were fairly clean, particularly those treated with paraquat. On the other hand, most of the drains were heavily infested. The poor state of drains is a result of inadequate machinery, which is usually employed for canal rather than drain clearance.

Conclusions

Some of the aquatic weed species reported in previous surveys have so far not been recorded in this survey. On the other hand, two species of *Potamogeton* not reported earlier were present in low density in some minor canals.

Although the investigations are not yet completed, there are indications that the occurrence and distribution of at least some aquatic weed species in minor canals may be related to water levels and discharges, wind, relative humidity, and water quality.

REVIEW OF AQUATIC WEED CONTROL MEASURES

A. M. Hamdoun

The Gezira Scheme is characterized by extensive irrigation and drainage systems that at present supply water to 800,000 hectares of crops annually. Soon after the construction of the Sennar reservoir, it was colonized by water weeds that originate on the mud-flats of the Blue Nile. The presence of aquatic weeds in the Gezira canals was reported in 1929, only 4 years after the irrigation system started to operate. The infestation gradually increased and with the present intensifified planting and irrigation, weeds now constitute a major constraint to the irrigation system. The problem is particularly acute in the minors, Abu XXs, and drains.

The most prevalent aquatic weed species in canals are: Potamogeton perfoliatus L., P. nodosus Poir, Najas pectinata (Parl) Magnus, Ottelia alismoides (L.) Pers., Vossia cupsidasa (Roxb.) Griff., Typha angustata (Bory and Chaub.) Forsk, Ipomoea aquatica Forsk., Cyperus rotundus L. and Cynodon dactylon L. These species propagate by seeds as well as vegetatively and some have underground structures that remain viable during the summer when most minors, drains, and Abu XXs are dry. They are therefore very successful in the colonization of the irrigation system throughout the growing season, particularly during the winter months when the water is clear.

Losses Caused by Water Weeds

There are no figures available on the direct or indirect losses to crop production due to aquatic weeds infesting the Gezira canalization system. The annual expenditure on weed clearance by the Ministry of Irrigation is now close to Ls. 700,000. The Gezira tenants also spend more than Ls. 500,000 in an attempt to control weeds in Abu XXs. In addition to these losses, some indirect losses are evident. Submersed water weeds decrease the flow velocity by reducing the cross-sectional area of the canal and by increasing friction. Furthermore, heavy infestations cause excessive water loss through evaporation, silting, and seepage. All these factors result in short supply of water for portions of the irrigated area at the time when cotton, groundnuts, wheat, and vegetables are still growing. During 1977-1978 season, about 5 percent of wheat and cotton in Wadi Shair and Matory Groups were hit hard by water shortages, mainly because of excessive growth of water weeds. Drainage canals are often choked by weeds and are rendered ineffective, especially in seasons of high rainfall. Drain blockage in July and August of 1978 contributed to the water logging of vast areas in the scheme.

In addition to economic losses caused by aquatic weeds, they also foster diseases among the inhabitants of the Gezira irrigated area. The distress suffered by large sections of the population as a result of malaria and bilharzia has not been assessed.

Weed Control

To maintain the efficiency of the irrigation and drainage canals, it is necessary to keep them free of weeds. Methods for the control of aquatic weeds include: manual pulling and cutting, mechanical cutting and extraction, the use of herbicides, and the use of biological control agents. These are discussed below.

1. Manual control

The Ministry of Irrigation employs teams of laborers on a permanent basis solely to control weeds in the heavily infested minor canals. Control is achieved by pulling, cutting, raking, chaining, and harvesting at intervals of 2-3 weeks. This practice used to be feasible and effective. However, with the present extensive canalization and drainage system, the scarcity of labor and the reluctance of these teams to work under hazardous conditions, this method of control is becoming expensive and is less effective than it used to be.

2. Mechanical control

The Ministry of Irrigation continuously desilts minor canals, using mechanical grabers, and in the process, weeds are uprooted and placed on the banks. Due to the shortage of machines and spare parts, this operation cannot be repeated in the same year in any one area.

A new mechanical device developed by the Agricultural Engineering Section of the Sudan Gezira Board has shown considerable promise in controlling weeds in minor canals. This implement consists of a steel bar with long hooks that extend into the bottom of the canal. When it is pulled by two tractors, one on each bank, submersed as well as emersed weeds are cut and shredded. It is, however, necessary to remove plant material manually. A variety of machines have been ordered from the Netherlands, but their efficiency in minors remains to be tested.

3. Chemical control

The use of herbicides has provided a partial solution to the aquatic weed problem in canals and drains. Paraquat at the rate of 0.4 kg active ingredient feddan (a.i./fed.) was extensively used in dry Abu XXs this season by the Gezira Board. Submersed, emersed, and bank weeds were effectively controlled. Repeated applications were necessary following later irrigations. Dalapon at 3-4 kg a.i./fed. and glyphosate at 1.5 kg a.i./fed. were equally effective in controlling most grass weeds in dry Abu XXs. Great care is generally necessary to avoid drift of the chemicals to adjacent crops.

Applied research on herbicides to control weeds in minors is complicated by several factors:

- Water is continuously flowing throughout the growing season when water weeds constitute a problem. Those canals are not likely to be closed during or after herbicide application;
- Herbicide-treated water cannot be used for irrigation soon after application; and
- Canal water is used for domestic purposes.

In view of these limitations, preliminary herbicide evaluation trials were carried out for the control of _T. angustata_, _Potamogeton_ sp. and _N. pectinata_. The results indicated that foliate sprays of amitrole at 3.0 kg a.i./fed., dalapon at 3.0 kg a.i./fed., glyphosate at 2.0 kg a.i./fed., and paraquat at 0.8 kg a.i./fed. were effective against _T. angustata_.

Dalapon, amitrole and glyphosate were more effective when applied between flowering and seed maturity. Paraquat was more effective when applied during the early stages of growth. It was evident in the tests that no treatment had a permanent effect upon numbers of shoot or growth; single applications are apparently not adequate and repeated applications are necessary. A follow-up treatment to amitrole or dalapon one month after either amitrole or dalapon caused shoot numbers to fall. Subsequently, initial population recovery was slower and the overall differences between populations increased for about 9 weeks after the paraquat treatments. Thereafter, shoot numbers in the non-paraquat-treated plots appeared to stabilize, while those in paraquat-treated plots continued to recover.

The dense canopy of _T. angustata_ in the minors limits the use of ground-spraying equipment because of unsatisfactory coverage of plants and difficulty in penetrating them. As a result, plants in the middle of the canal receive little or no spray.

Paraquat at 1.0 kg a.i./fed., diquat at 1.0 kg a.i./fed. and ametryne at 1.6 kg a.i./fed. were tested on submersed weeds in stagnant canals. All three herbicides showed considerable promise in controlling weeds.

4. Biological control

The Chinese grass carp (Ctenopharyngodon idella Val.) is a fast-growing and economic food fish. It is considered one of the most promising biological means of reducing infestations of aquatic weeds. Following the introduction of fingerling grass carp at the Experimental Fish Farm at Shagarra in 1975, a limited number of fish (average weight 250g) was introduced in 1976 into an enclosed section of Barakat minor that had been heavily infested with Potamogeton sp. and N. pectinata. Within a few months, all submersed aquatic vegetation was eaten, and thereafter the fish were supplied with Potamogeton sp. from other infested canals. The individual weight of some fish is at present over 3 kg. The fish are surviving in the minors and no predators have been observed. The success achieved so far indicates that this species can be safely introduced in the minors.

Another effective biological approach to the control of aquatic and semiaquatic weeds is the use of competitive plants to displace noxious species. The Gezira tenants have discovered that growing pigeon pea (Cajanus cajan L.) and Lubia (Dolichos lablab L.) along the banks of Abu XXs and Abu VIs reduces weed infestation by ditch bank grasses. This practice is now widely adopted throughout the irrigated schemes.

The Agricultural Research Corporation, in collaboration with the Ministry of Irrigation, has recently constructed a quarantine nursery for growing dwarf spike-rush (Eleocharis coloradoensis (Britt.) Gilly), which will be tested for the control of submersed aquatic weeds such as Potamogeton sp. and N. pectinata.

Conclusions

The problem of aquatic weeds is mainly encountered in minors and Abu XXs. The present control methods, though successful in limited instances, have not proved adequate. The most effective weed management would involve adoption of an integrated approach which combines mechanical, chemical, and biological methods.

Improvement in current and future control practices could be achieved through intensive research in biology, ecology, and taxonomy, and on the distribution of biological control agents such as fishes, insects, and pathogens.

Herbicides and their associated application techniques and side effects should be studied. Different types of mechanical equipment should be tested. In order to achieve this objective, a team consisting of botanists, chemists, aquaculturists, engineers, entomologists, and pathologists should undertake a research project for 4-6 years. The outcome of this investment will lead to a better understanding of the problem and to effective and lasting aquatic weed management.

SCHISTOSOMIASIS IN GEZIRA IRRIGATION CANALS

Mutamad Ahmed Amin

The economic justification for the development of water resources in the Sudan is beyond argument. There is a need for more water to meet the growing demands for food and energy. However, the development of such water resources has led to modifications in the environment that favor the spread and multiplication of disease vectors and have produced dramatic increases in the prevalence of certain diseases. In no instance has a water resources project been impeded in its planning or early development because of the waterborne diseases that could ensue. Schemes implemented without any preventive measures have often failed to develop to their full potential. This regretable state of affairs appears to stem from two main causes:

1. A failure of communication at all levels between the several disciplines and bodies involved in water resource development programs; and
2. A lack of awareness on the part of planners, engineers, economists, and administrators of the inevitable spread of waterborne diseases like malaria and schistosomiasis, as well as a lack of conviction on their part of the socioeconomic importance of these diseases.

A clasic example of this situation is the Gezira Scheme. Before irrigation, the area was an arid, fertile plain with scanty seasonal rainfall. Malaria and schistosomiasis were not a problem at that time, after the establishment of canalization, both diseases appeared and are now endemic.

This report gives an account of the spread of schistosomiasis in the Gezira Scheme and discusses the environmental factors that have favored the multiplication of the disease vectors.

Schistosomiasis

Schistosomiasis, or bilharzia, is one of the most important parasitic diseases of man in tropical and subtropical Africa, East Asia, the Caribbean Islands, and South America.

The disease is caused by infestation with parasitic blood flukes transmitted by aquatic snails. It is a typical example of a disease facilitated by man. The disease was not known in the Gezira before irrigation and existed only along the White Nile.

Three years after the establishment of irrigation by canalization (1928), snail intermediate hosts appeared in the system. Egyptian laborers infected with S. haematobium (urinary type) and White Nile farmers infected with S. mansoni (intestinal type) were brought to the scheme together with uninfected people. This potent combination of snails and infected subjects led to the establishment of the disease.

Schistosomiasis is now considered to be the fourth most important public health problem in the Sudan. In the Gezira Scheme, recent surveys indicate that the general infection rate is 60-70 percent and can be over 90 percent in school children aged 8-15 years.

It was estimated that 9 percent of agricultural productivity was lost as a result of absenteeism due to ill-health or during treatment. In terms of gross national production from agriculture, it has been calculated that the annual loss due to schistosomiasis alone would amount to 30 million Sudanese pounds.

The factors that contribute to the high prevalence of schistosomiasis include:

1. The design of the scheme, the irrigation practices, and the water management techniques;
2. Ecological factors, such as temperature, pH, salinity, and aquatic weed growth;
3. Human factors such as defecation, urination, water contact activities, and population movements; and
4. Ineffective control measures.

It was against this background of prevalence and wide distribution of the disease that the Ministry of Health requested the development of an effective procedure for control. Towards this end, a pilot project was established with the following immediate objectives:

1. To evaluate the existing snail-control measures;
2. To collect epidemiological and biological data to serve as a basis for a study of the dynamics of schistosomiasis transmission, so that predictions can be made as to the efficacy of control measures;
3. To assess the public health significance of schistosomiasis under defined conditions of transmission; and
4. To train medical and paramedical personnel in bilharzia work.

The data collected by the bilharzia team was used to formulate a comprehensive, integrated approach for the control and prevention of malaria and schistosomiasis and other water-associated diseases in the Gezira and Rahad Schemes. This program was designed under the sponsorship of the World Health Organization and other international agencies.

The comprehensive strategy will make use of available methods of control, including environmental management, biological and chemical control of vectors, and chemotherapy. Rehabilitation and completion of the water supply and sanitation measures, strengthening of health services, and promotion of community participation will also be important components, as well as improvement of irrigation and agricultural operations and practices. Concurrently, newer, more effective and economical methods of control will be developed and field-tested.

MALARIA IN IRRIGATED AGRICULTURE

A. M. Haridi

Malaria is considered the major health problem in the country. Its endemicity ranges from hypo-endemic in northern Sudan to holo-endemic in the south and its control is given top priority in the country's health program.

Malaria Transmission

Malaria transmission in the Sudan can be divided into natural transmission and man-made transmission. Man, in his endeavor to improve his standard of living, alters the environment by construction of dams and irrigation canals. Modern agriculture produces ecological changes that favor malaria transmisison through:

- Increased breeding potential for mosquito vectors of malaria;
- A microclimate that supports malaria transmission; and
- Resistance to insecticides.

Because of these factors, malaria transmission in irrigated areas has changed from seasonal to perennial, and endemicity ranges from meso-endemic to hyper-endemic.

Mosquito Breeding

Breeding of mosquitoes is facilitated in irrigated areas by increased water in the fields and in the canals.

The Weed Factor in Mosquito Breeding

Weeds growing in canals favor mosquito breeding for the following reasons:

- The water course is obstructed, slowing down the flow and creating stagnation. Stagnation is greatest in Abu XXs and minor canals and mosquito breeding is rampant.

- Dense vegetation in the canals and other breeding sites reduces the efficiency of the control measures. The larvicides, in an oil base, do not spread evenly on the water surface, chemical sprays cannot penetrate to the target, and free movement of animal life is hindered, reducing the effectiveness of larva-eating fish and other predators.

Weeds are essential for the breeding of certain mosquito species such as Anopheles pharaensis, which cannot propagate in their absence. This species is found in its highest densities in irrigated areas, especially in the winter season when irrigation is at its maximum. However, An. paraensis is not an important vector of malaria in the Sudan. An. funestus breeds in water covered with vegetation. This species is more common in the southern part of the country and is an important vector of malaria. An. gambiae, the principal vector of malaria in northern Sudan, prefers to breed in clear, stagnant water. It is found in heavy densities in Abu XXs, where the water stagnates as a result of dense vegetation.

The weed-mosquito association is greatest between Monsonia sp. and water lettuce in the White Nile. The larva belonging to this group attaches itself to the roots of these plants in order to get oxygen. Monsonia is an important vector of filariasis.

Weed Control

Weeds represent a permanent potential hazard to the national health by assisting in the propagation of disease vectors. The importance of vegetation clearance as an environmental management measure for control of mosquitoes and snails needs to be stressed; irrigation canals and drains should be kept free of weeds and other plants that grow profusely in the beds and banks.

Coordination between irrigation, agriculture, and health authorities is essential to achieving this purpose.

STUDIES OF THE CHINESE GRASS CARP AND ITS EFFICIENCY AS A BIOLOGICAL CONTROL AGENT FOR AQUATIC MACROPHYTES

Thomas T. George

In the 102nd Annual Meeting of the American Fisheries Society and the International Association of Game and Fish Commission (Hot Springs, Arkansas, September 10 - 15, 1972) William M. Bailey, Jr. posed the following question:

> "Should we continue to add to the pollution of our water with chemicals which have, in some cases, known harmful side effects on our environment and in other cases unknown side effects, which actually may kill the major oxygen producers on earth, or should we use an alternative method of aquatic weed control, provided by nature, which has exhibited no environmental harm?"

In fact, nature has provided us with a herbivorous fish, known variously as the Chinese grass carp, or the white amur, (*Ctenopharyngodon idella* Val.), which could be used as a biological control agent for aquatic macrophytes as well as a food fish. Studies and observations on the feeding habits and efficacy of the grass carp in a number of countries, including China, Japan, Taiwan, Israel, Thailand, Malaysia, India, Pakistan, the USSR, USA, UK. Rumania, and Hungary, have supported the view that the fish has excellent potential for controlling aquatic weeds. Recently the grass carp has also been introduced to Sudan and the purpose of this paper is to present a detailed account of the grass carp and its efficiency as a biological control agent for aquatic weeds in irrigation canals. Comparison is also made between observations on the grass carp in Sudan and reports from other countries.

The Chinese Grass Carp

Distribution

The Chinese grass carp, which belongs to the family Cyprinidae, originated in the Yang-tze River in China and is also a natural inhabitant of the middle and lower sections of the Amur River which forms part of the boundary between Manchuria and the Soviet Union. The grass carp was introduced into Japan in 1878, but it was only in 1948 that it started to breed naturally in various parts of the Tone River system, the longest in Japan. However, the habitat of the grass carp is now considered to be the Asian continent, where it is widely distributed from the Kakuryu River system in the north to the rivers, streams and lakes of Northern Vietnam in the south (Asano, 1974).

External Features

The grass carp has an elongated body that is moderately compressed laterally and covered with uniformly large and heavy scales (numbering 42 along the lateral line). The body of the fish is dark grey to olive on top and silver on the belly; all fins are dark, and the base of each scale is dark brown. The grass carp has a broad head with a short, round snout. The upper jaw is slightly longer than the lower.

Internal Features and Biology

The grass carp has a toothless mouth but possesses strong, specialized pharyngeal teeth. These teeth occur in two rows, the upper row consisting of two small teeth on either side and the lower one of strong comb- or file-like teeth. In fish less than 30 cm long, the lower pharyngeal teeth tend to have a serrated cutting surface, while in larger fish, the teeth are thicker and tend to have a double flattened serrated cutting and rasping edge that enables the fish to masticate the leaves of tough terrestrial plants and fibrous grass. The serrated nature and the action of these structures make it obvious that this fish is a typical herbivore, well adapted to cutting and mascerating plant material.

The grass carp feeds mostly on zooplankton (rotifers and crustaceans), unicellular algae, and occasionally chironomid larvae until it is about a month and a half old. It becomes phytophagous, feeding primarily upon submersed and floating aquatic weeds and filamentous algae (Nickol'skii, 1956; Konradt, 1966) when it reaches a length of 3 cm. Active feeding begins when the water temperature rises above

10°C, becoming intensive at temperatures above 16°C and reaching an optimum at about 26°C. Grass carp weighing less than 1.2 kg may eat several times their body weight in plant material daily, while larger fish, under favorable conditions, consume their body weight in food each day.

The digestive tract of the fish is short, only 2 - 3 times the body length. The gut enzymes are lipase, amylase, and proteases. Because of a short gut and the absence of enzymes for cellulose digestion, the grass carp consume large amounts of plant material (Hestand and Carter, 1978). In experimental ponds, 50 kg of fresh Hydrilla was consumed to produce 1 kg of fish flesh. However, only about 65 percent is egested in the form of dense pellets that provide "green manuring" of the water.

Grass carp have a life span of 12 - 15 years and grow quickly. Because of the shorter food chain, they are able to convert aquatic weeds into fish flesh very efficiently, resulting in high yields. They generally attain a weight of 1 kg in 1 year, 3 kg in 2 years and 5 kg in 3 years. The maximum length reported for a single speciman is 120 cm, with a weight of 32 kg. On a dry weight basis, grass carp filets contain approximately 80 percent crude protein (18 percent on a wet weight basis), making them an excellent source of high-quality protein. The flesh is white, firm, flaky, and non-oily (Bailey, 1972).

Grass carp are very active. They tolerate slightly brackish water and can resist the effects of low oxygen tension and restricted space.

In its natural habitat in China, the grass carp reach sexual maturity in 3 - 4 years and weight 3.6 to 5.9 kg (Lin, 1935; Chen and Lin, 1935). In Europe maturity is reached in 4 - 7 years, and in the Moscow area at 10 years of age (Woynarovich, 1969). Males mature one year earlier than females. Inaba, et al. (1957) estimated 485,000 eggs in a grass carp 88 cm long and weighing 7.1 kg.

The grass carp do not spawn outside their native range though this has only occurred in Taiwan and Japan (Tang, 1960; Kuromuma, 1954). Natural spawning occurs from May to August and is influenced by temperature (25° - 30°C) and fluctuating water levels (60 cm - 1.2 m) over normal level (Inaba, et al., 1957). The spawning activity is carried out by a group of several males and females. The eggs are released in the current in two to three stages, with the largest volume released in the first round and are immediately fertilized by the males. Development occurs as the semi-bouyant eggs float downstream with the current.

The eggs are of a characteristic yellow and deep golden-brown color. The diameter of the egg is 1.5 mm when it is laid, but after absorbing water it swells to about 5 mm. One hour after fertilization, egg division takes place; by 18 hours the eyes become visible, and hatching commences after about 32 - 40 hours at a water temperature of 27° - 29°C (Nickol'skii, 1956). As mentioned, the eggs are semi-bouyant and when artifically incubated, they must be agitated or else the fish die before hatching or become deformed and die soon after hatching (Bailey, 1972).

Introduction of the Grass Carp into Sudan

Before deciding to introduce the grass carp into Sudan, the Fisheries Research Center objectively determined:

- That there is a real need for the proposed introduction; and
- That the grass carp would have a desirable ecological and economic impact (George, 1975[a]).

Justification for introducing the grass carp into Sudan includes the need for new sources of protein and for controlling aquatic weeds in national waterways. These needs are discussed below.

Polyculture

Fish culture or freshwater aquaculture for increasing animal protein started in 1953 at the Experimental Fish Farm at Shagarra using a single indigenous species, Sarotheradon niloticus (Tilapia). In such a mono-culture system, the production of fish per hectare is rather low. But the efficiency can be increased by applying to the pond microcosm the science of ecology. A dramatic increase in yield can be obtained through polyculture, the rearing of several species not naturally competitive, to make more efficient use of the total pond environment. In polyculture, a body of water is considered a three-dimensional growing space producing a number of different fish food organisms so that stocking single species of fish wastes not only space, but food (Bardach, et al., 1972). Thus, by introducing the grass carp and culturing it along with other omniverous species and/or bottom feeders like the common carp, there will be a saving in feed as well as space, along with an increase in production of animal protein in a given area that makes the operation economical (George, 1974 Unpubl.).

Aquatic Weed and Health Problems in Minor Canals, "Haffirs," and Fish Ponds

The development of agriculture in any country is a function of the availability of water. As water channels are created to provide this water, the area offered to growth of aquatic weeds increases. The result in Sudan has been aquatic weed and related health problems.

The minor canals of Gezira (3,856 km), Managil (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 Naama (85 km) provide good conditions for macrophytic aquatic weed growth because their construction, design, and sluggish flow make them practically stagnant pools. These canals are thus heavily infested by plants anchored in the mud, such as *Potamogeton perioliatus* L., *P. nodosus* Poir; *P. crispus* L.; *P. pectinatus* L.; *Chara globularis* Thillier; *Najas pectinata* (Parl.) Magnus; and *Otellia alismoides* (L.) Pers., and those inhabiting the canal banks (such as *Panicum repens* L., *Cyperus rotundus* L., and *Ipomea repens* Poir. (Beshir, 1978). As a result, the following problems exist:

- The aquatic weeds accelerate the silting of the minors as well as slowing water flow;
- The weeds and foliate breaking the water surface enhance mosquito breeding by protecting the larvae from wave action and larvivore fish, thus interfering with mosquito control procedures; and
- Aquatic weeds harbor the vector snails Bulinus and Biomphalaria of Schistisoma, which find admirable sheltered habitats with rich supplies of food and surfaces suitable for oviposition.

Similar problems occur in the haffirs, which in western Sudan are used for storage of drinking water.

Another type of weed occurring in fish ponds is the algal blooms. These usually render waters thick green or blue-green in color and often cause quicker and more drastic calamaties than other aquatic weeds. Rotting algae cause oxygen depletion and accumulation of toxins in the water, conditions which together bring about mass mortality of aquatic life (Ramachandran and Ramoprobho, 1968).

The Government spends a great deal of money annually in manual removal of aquatic weeds and eradication of mosquito larvae and bilharzia vector snails. The Fisheries Research Center, recognizing these national problems, recommended the introduction of grass carp into Sudan.

Pesticides and Pollution Problems in the Minor Canals

Due to application of DDT and Dieldrin, *Anopheles gambiae*, the principal malaria vector in the Sudan, has developed double resistance to these chlorinated hydrocarbon insecticides. Consequently, the organophosphorous compound Abate was introduced as an alternative larvicide in the Gezira canals (Abdel Nour, 1972; Haridi, *et al*., 1973).

Until very recently, copper sulfate was used at a concentration of 30 ppm, followed by continuous application at 0.125 ppm to create a chemical barrier (Sharaf and El Nour, 1955; El Nagar, 1958; Amin, 1972[a]). Trials were undertaken for replacing copper sulfate by N-tritylmorpholine (Frescon) applied at a dose of 0.045 ppm (Amin, 1972[b]). Investigations indicated that Frescon causes acute oxygen depletion in water, resulting in heavy fish mortalities (El Moghraby, 1968 Unpubl.). A critical appraisal of the water pollution problem in the Gezira canals, with particular reference to aquaculture, is given by George (1976). The status of pollution in the Sudan, its control, and the protection of the living resources is given by George and El Moghraby (1978).

The Fisheries Research Center, recognizing this situation, has been faced by the difficult and perplexing question of how the aquatic weeds may be removed at a cost that the population of a developing country can afford and that will not have hazardous effects on the environment. The reply to this question, based on investigation, was "Introduce the grass carp!" (George, 1975[a]).

Introduction of the Grass Carp

A history of the introduction of the grass carp into Sudan, including the results, follows.

The Experimental Fish Farm, Shagarra. The Minister of State for Agriculture, Food, and Natural Resources granted the Fisheries Research Center government permission to introduce into Sudan two exotic species, *C. idella* (Val.) and *C. carpio* L. The Government of India presented to the Government of Sudan a gift consignment of the two species.

On 1st January, 1975, 10,000 fingerlings of grass carp ranging in size and weight between 3.3 - 4.7 cm and 0.4 - 1.4 g arrived at Khartoum airport from Calcutta. The entire consignment was put in fifty tins, each containing a polythene bag, a little water, and the fingerlings. Before being introduced into the fish ponds, the fingerlings were acclimatized to conditions in Sudan by adding Nile water at a temperature similar to that in the polythene bag, then given a bath in accrivlavin as a hygenic measure. For two months the fish were fed on rice bran and oil cake (George, 1975[b], [c], 1976[b]).

The Minor Canals of Gezira. In November 1975, the Workshop on the Management and Utilization of Aquatic Weeds in the Sudan and the Nile Basin, sponsored jointly by the National Council for Research and the U.S. National Academy of Sciences, formulated the following recommendation:

"Recommendation 8--Herbivorous Fish

Many countries, especially in Asia and Europe, are now beginning to use the grass carp, C. idella, to clear submersed weeds from canals. This fish converts the weeds directly into highly nutritious food that is well liked, for its flesh is so delicious that it is ranked among the top best tasting fish in the United States. After the fish's first week of life, the grass carp eats only plants. It eats submersed weeds of the type that are so troublesome in canals in the Gezira and Egypt. It will nibble on water hyacinth but affects the plant little. In the State of Arkansas, USA, whose waters formerly were choked with weeds, the fish has been widely released during the past four years. Today, the State is reported to have no submersed weed problem whatever.

Scientists in both the Sudan and Egypt have already introduced fingerlings of this fish.

The workshop recommends that trials leading to releasing the fish into appropriate canals be undertaken rapidly."

This recommendation convinced the technical committee of the Fisheries Research Center to permit the introduction of the grass carp into one of the minor canals in the Gezira.

The grass carp were introduced on three different occasions so that if mortality occurred, the loss would not be great. Male common carp were also introduced to see if breeding would take place; it did not. The following table gives an account of the fish introduced.

Date	Species	Number	Av. Total Length (cm)	Av. Weight (g)
March 3, 1977	grass carp	34	29	200
	minor carp	57	--	---
May 21, 1977	grass carp	52	32	250
July 10, 1977	grass carp	25	27.4	170
	scale carp	17	--	---

Wire mesh was fixed on the water pipes at two concrete bridges about 500 meters apart along the minor canal (Soriba), to contain the fish. The grass carp (34 fish) and male minor carp (57 fish) were introduced on March 3, 1977 in this area. In the beginning of May 1977 two wire mesh partitions, enclosing a distance of 32 meters, were fixed in the same canal and on May 21, 52 grass carp were introduced in this area; on

July 10, 17 male scale carp were introduced in the same area and 25 grass carp were stocked in other portions of the canal extending south of the wire mesh and the concrete bridge, a distance of 113 meters. The fish were transported by car in tins with a polythene bag containing water and in a large barrel. Before the fish were released into the minor canal, they were given a bath of accrivlavin solution.

A fish pond was also dug and during August about 25 grass carp were removed from the minor canal into this pond for observation of their mature state (George and Babiker, 1977 Unpubl.).

Research Objectives. The basic objectives of the research program on the grass carp at the Experimental Fish Farm and in the Gezira are as follows:

- To conduct studies on the compatibility and competition of the grass carp and other indigenous species in fish ponds and in canals;
- To assess the efficiency of grass carp in controlling aquatic weeds in the canals, with a view to improving the rate of flow and to assist indirectly in the control of vector snails of bilharzia;
- To determine if the present level of pollution of the Gezira minor canal with pesticides is within tolerable limits to the carp;
- To determine if the grass carp reproduces in ponds and minor canals; and
- To determine the effect of grass carp on plankton and water quality.

Results of Grass Carp Introduction

Acclimatization

Although the grass carp is native to the rivers of China, Manchuria and Siberia which flow into the Pacific Ocean from latitudes 50° N to 23° N, it has acclimatized well in the warm tropical waters of Sudan, both in the ponds of the Experimental Fish Farm and the minor canals of the Gezira irrigation system at Wad Medani.

Control of Aquatic Macrophytes

Since the introduction of the grass carp, research has been in progress to evaluate its efficiency in controlling aquatic macrophytes. Investigations carried out and the results obtained are briefly outlined below.

When the grass carp was introduced into the minor canal, there was a heavy infestation of aquatic weeds, mainly

Potamogeton spp. Over a period of about a month, a remarkable reduction of aquatic macrophytes occurred. This did not happen in the adjacent section of the canal without grass carp. The vector snails of bilharzia (Bulimus and Biomphalaria), which adhere mostly to the leaves of weeds (84 percent on leaves, 16 percent on stem) were eaten along with the leaves. As the grass carp continued to feed, the leaves were nipped off while the stems floated. When 250 floating stems were examined for snails, only 23 snails were recorded; 250 stems with attached leaves would normally contain not less than 500 snails. Further, the floating stems were eaten later when the leafy plant material was depleted.

As already mentioned, male common carp were introduced along with the grass carp to see if breeding would take place. Also, the common carp has a subterminal mouth with projectable lips and barbles to feel about the bottom. It is thus adapted to grasping, rooting, and pulling up the vegetation, thereby muddying the pond. Unlike the common carp, the grass carp feeds from the top downward "mowing" off the vegetation rather than rooting it up and muddying the bottom. The objective of this operation was for the common carp to roil the bottom mud with the resulting muddy waters preventing submerged aquatic weed growth by shading; aquatic weeds were then introduced daily from other areas to feed the grass carp in the confined experimental area. It was also our intention to investigate whether the muddying produced by the common carp has any effect in reducing vector snails. Tryon (1954) and Threinen and Holms (1934) attributed weed control by the common carp to the muddying of waters by its feeding habits. Use of this species to control filamentous algae, especially Pithophora sp., was reported by Swingle (1957), Grizzoll and Neely (1962), and Shell (1962), and Avault (1965).

In the ponds of the Experimental Fish Farm at Shagarra, the grass carp has been observed to consume a daily variety of aquatic weeds regardless of the fact that commercial fish food was also added to the pond. Bailey (private communication, 1972) stocked grass carp in a pond where pondweeds (Potamogeton spp), coontail (Ceratophyllum demersum), duckweed (Lemna spp.), Pithophora, and Chara were growing. All these weeds were readily consumed in a definite order of selection, and after the more succulent submersed weeds were destroyed, the fish was observed leaping halfway out of the water to reach leaves of smartweed (Polygonum fluitans) and several other terrestrial plants. Some trials on weed preference of grass carp were undertaken. It has been observed that P. pectinatus is preferred to P. modosus, (George and Babiker, 1977 Unpubl.).

Compatibility and Completion

The grass carp did not show any aggressive behavior toward the indigenous or exotic species and growth rates were normal for all fish. Furthermore, the fecal matter acts as "green manuring" of the water body, thus increasing the volume of natural food for other species.

In a pond at the Experimental Fish Farm where grass carp is cultured with common carp, it was observed that the latter reached a size of 73 cm and a weight of 6.1 kg in three years' time. Nikol'Skü and Verigin (1968) observed that herbivorous fish have increased the fish production of ponds by 50 - 100 percent.

At the Shagarra Experimental Fish Farm the grass carp did not compete with other species for food. It ate all the weeds supplied daily, despite the addition of other supplementary feed such as rice bran and oil cake. Kilgen and Smitherman (1970) observed that if the weeds were removed, the grass carp did not deplete the many Chironomid larvae found in the pond bottom. They concluded that the grass carp's feeding habits are not at all similar to those of other fish and that they do not pose a threat as a competitor for food organisms eaten by game fish. Actually, a look at the morphology of the feeding parts (Bailey, 1972), should allay fears that this fish could be a predator or competitor, or that it could muddy the water and have an ill effect on sight feeders. The typical large mouth for capturing prey and the teeth for holding them are missing on the grass carp. The mouth is terminal and adapted to biting rather than rooting; thus the fish does not root or muddy the water.

Plankton and Water Quality

In Sudan, it has been observed that the oxygen level drops significantly when the water in the fish pond containing grass carp is not changed for a long time. Still further studies are needed to determine whether, under Sudanese conditions, the grass carp increases plankton or not.

Walker (1971) reported that plankton blooms invariably develop in water where grass carp is introduced. Boyd (1968), Burton (1971), and Carter and Hestand (1977), reported that since aquatic macrophytes act as a reservoir for inorganic nutrients, their rapid destruction results in the recharging of the water with nutrients; these nutrients are then available for increased phytoplankton production, which could be more damaging to water quality than dense strands of macrophytes. It would appear that the introduction of the grass carp into an aquatic ecosystem could cause major changes in the system. However, Hestand and Carter (1978) have recently documented the effect of grass carp on phytoplankton communities. According to their observations, the nutrients resulting from the control of macrophytes by grass carp were not available to phytoplankton, since no appreciable changes in water quality was found. They have attributed this to two factors. First, the grass carp releases high quantitities of ortho-phosphate, iron, and magnesium that are precipitated by or with organic acids. Once they reach the sediments at the bottom, these nutrients become bound in complex organic molecules that are not available to phytoplankton; rooted macrophytes could utilize these nutrients, but by elimination of the macrophyte "nutrient pumps" the grass carp causes an increase in the sediment nutrient concentration and thus indirectly decreases phytoplankton production. The second factor that affects the availability of nutrients to phytoplankton is the conversion of plant material to fish flesh. Earlier workers such as Ahling and Jermelov (1971) found no clear influence of grass carp on phytoplankton and no influence at all on zooplankton. However, Grygierik (1973) observed more daphnids in fish production ponds with grass carp, probably as a consequence of more bacteria.

Tolerance to Pollution and Various Physicochemical Factors

The waters of the minor Gezira canals are polluted with pesticides (George, 1976; George and Moghraby, 1978), but in spite of this, no grass carp mortalities have as yet been recorded. However, more data will be made available on this subject.

Preliminary studies indicated that the grass carp requires an oxygen concentration level of 3 ppm for normal behavior, but it can tolerate an oxygen level as low as 1 ppm. Singh, et al. (1967) worked on various physicochemical factors of water in relation to growth of young grass carp ranging in size from 22 - 125 mm and found that they can tolerate a temperature range of 16° - 40°C, turbidity 124 - 215 ppm. pH 5.0 - 9.0, dissolved oxygen 1.0 - 28 ppm, total alkalinith 88 - 690 ppm, salinity 7.5 - 8.0 percent, free ammonia up to 3.5 ppm, free chlorine up to 0.08 ppm, and free sulphide up to 4.0 ppm.

Reproduction

Outside its native China, except in several widely scattered locations of diverse physiography (Stenley, 1976), the grass carp has failed to breed naturally. This has been true of the grass carp in Sudan. However, it should not be considered a drawback in the culture of the grass carp for the following reasons: 1) attempts to breed the fish by hormone injections proved successful and so its dibribution can be fully controlled; 2) the fish has a very high fecundity, and if all its eggs were released it might become a pest.

In Sudan, the female grass carp reached full maturity at 3.5 years; the males started oozing milt a year before. The fecundity of a 35 cm female fish weighing 3.5 kg was 730,000 eggs. Prikhod'Ko and Nosal (1963) reported that grass carp weighing 3.0 - 3.8 kg in Nivk fish farm in the USSR showed absolute fecundity ranging from 180,000, 295,000, to 442,750, when the fish were in different stages of maturity. In India, 308,800 to 618,100 eggs were found to be the fecundity of grass carp in the range of 73.8 - 79.2 cm long and weighing 4.8 - 7.0 kg (Alikunhi and Sukumaran, 1963).

The spawning season of the grass carp in Sudan seems to extend from July to mid-August; males were observed to ooze milt readily from June onward and as early as April. However, during July/August an attempt was made to breed the grass carp artificially by hormone injections, using methods followed in the USA and India. The dry method of artificial fertilization was employed after the females were administered hormone injections at the recommended intervals. To effect contact between eggs and sperm, the stripped eggs and milt were placed in an enamel pan and carefully stirred with a large feather. The fertilization process was completed within about a minute. Immediately thereafter the eggs were washed with water to remove the fluid mucous discharged from the cavities of the breeders. They were then placed in glass aquaria with circulating water flow and aeration.

The operation was successful, but while the eggs were in the final states of development (brisk movement), the electricity failed and death resulted to all the fertilized eggs.

Discussion

The Fisheries Research Center introduced grass carp into the country because of a) the low production per hectare of fish in aquaculture; and b) excessive weed growth in irrigation systems. Problems associated with aquatic weeds are:

1. Silting and slowing of the water flow rate;
2. Promotion of mosquito larvae; and
3. Infestions of vector snails of Schistosoma.

These problems fall within the scope of interest of various agencies such as the Fisheries Research Center, the Ministry of Irrigation, the Malaria Section of the Ministry of Health, or the Central Medical Research Laboratory.

The Fisheries Research Center believes that the grass carp will contribute greatly to the solution of all the problems mentioned above. An ideal program for solving these problems should involve the concerned bodies so that they can integrate their efforts to promote biological control.

Biological control will not totally erradicate the weeds, and this should not be the measure of success. In nature, a balance is maintained by plant-feeding insects, snails and other factors. Biological control agents are selected to tip this balance and reduce the plant's vigor, but not necessarily to destroy it completely. Other species of fish that feed directly on snails could also be introduced to solve the problem of bilharzia, including the black carp, *Mylopharyngodon piceus*, and the redear sunfish, *Lepomis microlophus* (Gunther). For improving water quality and promoting polyculture, the silver carp *Hypophthahmichthys molitrix*, a phytoplankton feeder, can be introduced.

Introduction of the grass carp does not mean that the role of alternate methods of weed control should be totally ignored, since these methods also have merit and may be useful in controlling weeds which are not controlled by the grass carp.

Generally, however, mechanical methods are, at best, very temporary and extremely expensive (Bailey, 1972). Chemicals are more practical for large-scale use, but many problems are associated with the use of herbicides in water. Moreover, although herbicides do control weeds in some areas, chemical control is only partially effective, temporary, expensive, and may adversely affect the environment. Walker (1971) states that repetitive use of chemicals is usually to the detriment of fish and other aquatic life. At present, no aquatic herbicide is registered that meets the criteria for all uses and none has been labeled with residue tolerance limits for drinking water, fish, and shellfish. Consequently, fish and shellfish from treated waters cannot be sold for human consumption. There is, therefore, need to evaluate the effects of herbicides on fish and their food organisms, as well as to collect data on the persistence of herbicide residues in water and bottom mud. Little work has been carried out in these areas (Tooby, 1971).

There are no such problems associated with using the grass carp as a biological control agent. The foregoing information supports this claim. Further evidence is supported by William M. Bailey, special projects coordinator and supervisor of hatcheries for the Arkansas Game and Fish Commission. Since 1971, Mr. Bailey has stocked about 350,000 fish (10-20-500 per acre) in well over 100 lakes, comprising more than 50,000 acres and has found no ill effects on fish populations; in some cases the populations have increased. Moreover, the cost of aquatic weed control using the grass carp is less than that for chemical and mechanical treatment.

Under Sudan conditions, introduction of the grass carp should prove to be successful, although additional facilities and much work will be required to reach our goals.

Conclusions and Recommendations

It is necessary that all methods of weed control--biological, mechanical, and chemical be considered in order to make use of the best combination for a particular environment. The following recommendations are made:

1. An ideal program for solving aquatic weed problems in minor canals should involve all the concerned bodies (Ministry of Health, Ministry of Irrigation, Fisheries Research Center and the Universities of Khartoum and Gezira) to integrate their efforts.
2. The ecological niches of the various fish species should be better understood so that biological control and polyculture technique can be practiced on a more informed basis. If research discloses that not all available niches are being filled, additional species, for example, _H. molitrix_ (for polyculture) and _M. piceus_ (for snails) should be introduced.
3. More effective means of spawning the grass carp must be developed. This means that better facilities should be made available for carrying out such work.
4. When breeding of the grass carp can be assured, experiments on the amount of aquatic vegetation consumed in relation to growth as well as stocking density should be carried out. This aspect has not been adequately studied.
5. Large-scale operational costs of using the grass carp as a biological control agent for aquatic weeds should be determined. This study should also consider the costs of alternative control means.
6. Research should be carried out on the effects of the grass carp on plankton and water quality.

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References

Abdel Nour, O. M. 1972. The insect problem in the Sudan. Symposium on Environment and Development in Arab Countries. ALECSO/NCR, Khartoum.

Ahling, B. and A. G. Jermelov. 1971. Weed control with grass carp in Lake Osbysjon. Swedish Water and Air Pollution Res. Lab., Mimeograph 15.

Alikunhi, K. H. and K. K. Sukumaran. 1963. Preliminary observation on Chinese carps in India. Proc. Indian Sci. Congr. 49(3):387.

Amin, M. A. 1972[a]. The control of schistosomiasis in the Gezira, Sudan: The use of copper sulphate and mechanical barriers. Sudan Med. J. 10(2).

______. 1972[b]. Large-scale assessment of the molluscides copper sulphate and N-trithylmorpholine (Frescon) in the north groups of the Gezira irrigated area, Sudan. J. Trop. Med. and Hyg. 75.

Asano, I. 1974. Special edition: fish seedling production technique, 4 grass carp. Farming Japan 8(1):36-39.

Avault, Jr., J. R. 1965. Biological weed control with herbivorous fish. Proc. 18th Annual Meet. South. Weed Conf., January 19 - 21, Dallas, Texas.

Bailey, Jr., W. M. 1972. American Fisheries Society, Hot Springs, Arkansas, September 10 - 15, 1972.

Bardach, J. E., J. H. Ryther, and W. O. McLarney. 1972. Aquaculture. The farming and husbandry of freshwater and marine organisms. New York: John Wiley and Sons, Interscience Publication.

Beshir, M. E. 1978. Gravity-flow irrigation and the spread of aquatic weeds in Sudan. Environmental Conservation 5(2):143-146.

Boyd, E. C. 1968. Some aspects of aquatic plant ecology. Reservoir Fisheries Society Symposium, Athens, Georgia, 1967, pp. 114-129.

Burton, A. M. 1971. Eutrophication of the St. Lawrence Great Great Lakes, pp. 233-243. In T. R. Detwyler: Man's Impact on Environment. New York: McGraw-Hill Book Co.

Carter, C. C. and R. S. Hestand. 1977. The effects of selected herbicides on phytoplankton and sulphur bacteria populations. J. Aquatic Plant Manag. 15:47-56.

Chen, C. S. and S. Y. Lin. 1935. The fish fry industry of China. Bull. Chekiang Prov. Fish Exp. Stn. 1(4):1-50 (in Chinese with English abstract).

El Nagar, H. 1958. Copper sulphate in the Gezira. J. Trop. Med. and Hyg. 16:231.

El Moghraby, A. I. (Unpublished.) Effect of Frescon on the water chemistry and fauna of the Gezira canals.

George, T. T. 1974. (Unpublished.) A note on the exotic fishes, C. carpio (L.) and C. idella (Val.) with particular reference to aquaculture in Sudan.

______. 1975[a]. The history and status of fish culture in Sudan and the urgency of its development into an industry. A review. FAO/CIFA Symposium on Aquaculture in Africa.

______. 1975b. The Fisheries and Hydrobiological Research Station introduces carp culture for Sudan ponds and farms. SUNA-Daily Bulletin - Issue No. 1431, pp. 7-8.

______. 1975[c]. Introduction and transplantation of cultivable species into Africa. FAO/CIFA Symposium on Aquaculture in Africa, CIFA/75/SR7.

______. 1976[a]. A critical appraisal of the water pollution problem in the Gezira canals with particular reference to aquaculture. Proced. of the 19th Annual Conf. of the Phylosophical Society of Sudan on Water Quality and Risks of Water Pollution.

______. 1976[b]. A note on the Chinese grass carp. A weed-eating fish for introduction to minor canals of the Gezira. Tech. Notes on Water Use. No. 10 ARC/R-FAO F.F.C.P.

______, and U. Babiker. 1977. (Unpublished.) Preliminary observations on the introduction of the grass carp into the Gezira minor canal (Barakat 3).

______, and A. I. El Moghraby. 1978. Status of aquatic pollution in the Sudan, its control and protection of the living resources. Sixth FAO/SIDA Workshop on Aquatic Pollution in Relation to Protection of Living Resources. FIR/TPKR/78/Inf. 20.

Grizzol, Jr., R. A. and W. W. Neely. 1962. Biological controls for water weeds. N. Amer. Wildl. Conf. 27:107-113.

Grygierlk, E. 1973. The influence of phytophagus fish on pond zooplankton. Aquaculture 2:197-208.

Haridi, A. M., M. A. Abood, and A. D. Nugud. 1973. Laboratory and field evaluation on the larvicide Abate against Anopheles gambiae in the Sudan.

Hestand, R. S. and C. C. Carter. 1978. Comparative effects of grass carp and selected herbicides on macrophyte and phytoplankton communities. J. of Aquatic Plant Management 16:43-50.

Inaba, D., M. Namura, and M. Nakamura. 1957. Preliminary report on the spawning of grass carp and silver carp in the Tone River, Japan, and the development of their eggs. J. Tokyo Univ. Fish. 43(1):81-96.

Kilgen, R. H. and R. O. Smitherman. 1970. Food habits of the white amur (Ctenopharyngodon idella) stocked in ponds alone and in combination with other species. The Progressive Fish Culturist 33(3):123-127.

Konradt, A. G. 1966. Methods of breeding the grass carp, C. idella (Val.) and silver carp, H. molitrix (Val). FAO World Symposium on Warm-water Pond Fish Culture FR:IV/E-g.

Kuromuma, K. 1954. Do Chinese carp spawn in Japanese waters? Indo-Pacific Council. Proceedings, Fifth Meeting, Bangkok, Thailand 22nd January - 5 February, 1954. Sections II and III.

Lin, S. Y. 1935. Life history of woon ue, Ctenopharyngodon idella (C&V). Lignon Sci. J. 14(1):129-33 and 14(2): 271-74.

National Academy of Sciences. 1976. The grass carp. In Making aquatic weeds useful: some perspectives for developing countries, pp. 15-22. Washington, D.C.: National Academy of Sciences.

Nickol,skii, C. V. 1956. Fishes of the Amur Basin. Moscow: Acad. Sci. USSR (in Russian).

______, ed. 1961. Special icthyology. Jerusalem: Israel Program for Scientific Translations. (Translated from Russian.)

Nikol'Skü, G. V. and B. V. Verigin. 1968. Results of research with herbivorous fish, basic objectives and direction of future investigations. New Investigation in Ecology and Biology of Herbivorous Fish, Nouka Moskva 12:19

Prikhod'Ko, V. A. and A. D. Nosal. 1963. Experience of artificial propagation of the grass carp in the Niva Fish Farm (in Russian).

Ramachandran, V. and T. Ramoprobho. 1968. Wood control in fish culture. Indian Farmer's Digest. 4(1).

Sharaf, E-D. and H. El Nour, 1955. Control of snails by copper sulphate in the canals of the Gezira irrigated area of the Sudan. J. of Trop. Med. and Hyg. 58:260-263.

Shell, E. W. 1962. Herbivorous fish to control Pithophora sp. and other aquatic weeds in ponds. Weeds 10:326-327.

Singh, S. B., S. C. Bonarjee, and P. C. Chokrabarti. 1967. Preliminary observations on response of young ones of Chinese carps to various physicochemical factors of water. Proc. Nat. Acad. Sci. 37(3):230-234.

Stenley, J. C. 1976. Reproduction of the grass carp (C. idella) outside its native range.

Swingle, H. S. 1957. Control of pond weeds by the use of herbivorous fishes. Proc. 5th Weed Control Conf. 10: 11:17.

Tang, Y-A. 1960. Reproduction of the Chinese carps C. idellas and H. molitrix in reservoir in Taiwan. Japanese Journal of Ich. 13, No. 1/2, Oct. 31, 1960.

Threinen, C. W. and W. T. Holms. 1934. Experiments and observations designed to show carp destruction of aquatic vegetation. J. Wildl. Management 18:24-51.

Tooby, T. E. 1971. The toxicity of aquatic herbicides to freshwater organisms. A brief review. Proc. European World Research Council. Third Int. Symp. Aquatic Weeds, Oxford, England, pp. 129-235.

Tryon, Jr., C. A. 1954. The effect of carp enclosures on growth of submersed aquatic vegetation in Pymatuming Lake, Pennsylvania. J. Wildl. Management. 18:251-254.

Walker, C. R. 1971. Chemicals and their effect on the aquatic environment. Proc. 24th Annual Meeting of the Southern Weed Science Society, Memphis, Tennessee.

Woynarovich, E. 1969. Techniques of hypophysation of common carp. In FAO/UNDP Regional Seminars on Induced Breeding of Cultivated Fishes, Calcutta FRi/1BCF/14:11 P.