FROM THE ARCHIVES

# Aquatic Weed Management: Some Prospects for the Sudan and the Nile Basin (1976)

Pages
64

Size
8.5 x 10

ISBN
0309335833

National Academy of Sciences; National Council for Research - Agricultural Research Council, Democratic Republic of the Sudan

# AQUATIC WEED MANAGEMENT:

## SOME PROSPECTS FOR THE SUDAN AND THE NILE BASIN

Report of a Workshop held
24 - 29 November 1975
Khartoum, Sudan

Co-Sponsors:

National Council for Research - Agricultural Research Council
Democratic Republic of the Sudan

National Academy of Sciences
United States of America

## Preface

This is a report of a workshop on the management and utilization of aquatic weeds in the Sudan and the Nile Basin. The workshop, held November 24 - 29, 1975, formulated recommendations addressed to one of the most critical environmental problems of the region--the weeds that infest the rivers, swamps, lakes and canals.

Jointly sponsored by the National Council for Research, Agricultural Research Council of the Sudan (NCR) and the National Academy of Sciences-National Research Council of the United States (NAS), the workshop was also attended by representatives of the Sudanese-German Water Hyacinth Control Project, and participants form Egypt, Ethiopia, West German, Indonesia and Mozambique.

The workshop deliberations were complemented by visits to Malakal in southern Sudan, a region where water hyacinth is most prevalent and serious; to the Jabel Aulia Dam close to Khartoum, which is infested with water hyacinth and other aquatic plants; and to the northern part of the Gezira scheme to observe weed-infested irrigation canals.

This, the first cooperative activity between the NRC and the NAS, arose from earlier discussions between representatives of the two organizations both in Washington and Khartoum. The participants would like to acknowledge the generous support of the NCR in providing the local facilities in the Sudan, including travel to and in the Malakal region, which greatly contributed to the success of the workshop; of the U.S. Agency for International Development (Technical Assistance Bureau, Office of Science and Technology), in providing support for the travel and staff costs for the NAS panel; of Ambassador Brewer and the AID Affairs Office, U.S. Embassy, Khartoum, for logistic and secretarial assistance; and of the Egyptian Academy of Scientific Research and Technology for sponsoring the participation of the Egyptian panel.

Recognition and thanks are due to the many individuals who contributed long hours and dedicated effort to make the workshop a success, particularly Dr. Mohamed Obeid and his colleagues who produced the pre-workshop report "Aquatic Weeds in the Sudan" describing the history, botany, and problems of the plants in the Sudan.

The report addresses both the water hyacinth problem and the problems of canal weeds, most of which are submerged and not readily seen, but which can render canals useless by blocking the water flow. It is written for administrators and scientists in all the countries of the greater Nile watershed and basin, but focuses particilarly on the Sudan as a model case for the region.

## TABLE OF CONTENTS

# CHAPTER I

## INTRODUCTION

The outbreak of water hyacinth in the Sudan is one of the environmental disasters of the century. The water hyacinth is a South American plant and before 1958 it had never been reported in the Upper Nile region. However, by the time it was first reported it occurred from Shambi, on Bahr El Jebel, to north of Kosti, a distance of about 700 km. By 1962 the plant had succeeded in infesting the whole stretch of the White Nile from Juba to Jebel Aulia Dam; the whole length of the Sobat River from its mouth eastwards up to Baro and Gila Rivers in Ethiopia and southwards up to Pibo River to Akobo; the whole length of Bahr el Zeraf; Lake No and Bahr El Ghazal; and many of the side lakes, khors, and tributaries, especially in the Sudd region. The picture today (Figure 1) is not different from that of the 1960s in spite of the expenditure of about a million Sudanese pounds per year for the control program (one Sudanese pound = US$2.50).

In the period of April to October vast amounts of water hyacinth plants drift north towards the Jebel Aulia Dam where they accumulate, completely covering the water surface. During this period, wind and current action continuously compress them into a thick carpet that people may walk on. After October, and due to the prevailing northerly winds, a totally different picture is encountered. The floating mats are observed in the main course between Jebel Aulia and Malakal. Along the banks of the Nile, in khors and in the swampy Sudd Zone further south, greater aggregations are encountered. Beyond the Sudd region and until Juba, very sparse small marginal aggregations prevail. With the onset of the flood season (June - July), the marginal population starts to show signs of newly extended lateral offshoots and mats of floating islands of water hyacinth are seen rapidly moving northwards. By then the gentle rise in level of the river starts to feed seasonal side streams and moisten extensive depressions. The Jebel Aulia Dam forms a physical barrier against the northward spread of the weed, but water hyacinth actually has been in the Nile Delta for many years and has never reached "plague" proportions. The spread of the plant in Egypt after 1972 appears to be a direct consequence of the slowing of the current of the Nile north of Aswan due to the erection of the High Dam. Water hyacinth is a common scene on the Nile in Cairo these days and was reported to have reached the town of El Menia in 1973.

## EFFECTS OF WATER HYACINTH INFESTATION

The spread of the water hyacinth in the Sudanese Nile system has had a number of harmful effects:

### Water Loss

The presence of water hyacinth on the Nile system causes an increase in water loss when compared to a free Nile surface. Under experimental conditions in the laboratory, the increase in water loss due to the presence of water hyacinth when compared with free water surface is two- to six-fold.

If one takes modest values of water loss based on laboratory experiments, then the total water loss due only to the presence of the water hyacinth could equal 7 billion cubic meters per year. This is equivalent to one-tenth the normal yield of the Nile. It is 1.78 times the amount of water expected to be provided by the first phase of the Jonglei canal. It is more than enough for the irrigation of the over 100,000 acres planned for sugarcane cultivation in the area of the White Nile, and it is also 7 times the water required for over 200,000 acres envisaged as the area most suitable for agricultural development in the Nile and Northern Provinces.

### Cost of the Control Program

Control programs are costly. Sudan's expenditure on water hyacinth control since its beginning in 1959 has been 6,829 million pounds (equivalent to US $19.12 million).

Rising costs of equipment and herbicides during the past four years is reducing the effectiveness of the program, as far less can now be achieved for the same amount of money.

### White Nile Pump Schemes

Along the White Nile there are more than 176 irrigation schemes serving a cultivated area exceeding 260,000 feddans.* The advent and spread of the water hyacinth blocks irrigation-pump inlets and clogs canals and other smaller irrigation water channels. Also, hydroelectric power plants have been blocked.

### Water Supply and Recreational Activities

Accumulations of water hyacinth along the river banks seriously affect the water supply for settlements. Decomposion plants near water supplies may make

---

* A feddan is slightly larger than an acre.

the water unsuitable for drinking. Boating, bathing, and swimming are no longer possible in many infested areas.

## Transportation

The Nile is the main transportation route between Northern and Southern Sudan. Difficulties experienced by steamers and boats since the advent of the water hyacinth have been frequently reported.

The steamers get damaged while maneuvering their way between dense mats of water hyacinth. This incurs

- Expenditure of money to purchase spare parts;
- Delay and irregularity of the steamers' trips;
- Delay in the transportation of goods;
- Reduction in the carrying capacity of the steamers, and
- Increased fuel consumption.

The River Transport Department has estimated that water hyacinth has caused a 50-percent increase (125 thousand pounds) over the amount normally allocated for boat maintenance; a 50-percent increase for spare parts purchase (70 thousand pounds); a 10-percent increase to meet general repair requirements (28 thousand pounds) and a 30-percent increase (10 thousand pounds) for fuel. The Department estimates that in total it loses about half a million pounds (US$ 1.25 million) annually because of water hyacinth.

## Fishing

Fish is an important item in the diet of the riverside dwellers, and, with meat prices increasing, fish is gaining greater importance in the diet of the inhabitants of most villages and towns. They fish with baskets or lines from the bank; the presence of the water hyacinth thus makes fishing impossible or very difficult. Many <u>khors</u> and side channels, which were formerly important fishing grounds, are now completely choked up. The Nilotics who fish by spear from canoes also find their task more difficult as they are pushed out of the shallows into the main stream where the current is stronger. Furthermore, in some areas the number of fish seems to have decreased, which could be due to water hyacinth blocking breeding grounds.

## Health Hazards

Water hyacinth plants provide suitable breeding sites for mosquitoes, which causes an increase in the incidence of malaria. Also, freshwater snails, like <u>Bulinus</u> and <u>Biomphalaria</u> species--which are intermediate hosts for bilharzia--find shelter and favorable growing conditions on the roots of water hyacinth.

Mats of water hyacinth harbour snakes; they also create conditions which force crocodiles to leave the river, causing unrest among the villagers.

## CHAPTER II

## RECOMMENDATIONS

### 1. REGIONAL COOPERATION

The Nile Basin waterways of Egypt, Sudan, Ethiopia, Uganda, Kenya, and Zaire are interconnected. Weeds in one will ultimately infect the others; organisms added to one for the biological control of aquatic weeds may also eventually spread to the others.

Many waterways are connected directly so that some water flows through several countries; others are linked indirectly by migrating waterfowl and by people passing between them.

If disasters such as the water hyacinth explosion are to be avoided in the future, it is crucial that the plant protection agency and other relevant agencies in each of the countries maintain close communication.

New species of aquatic weeds have yet to reach the region (see next recommendation). When one first arrives in the waters of one nation, massive programs sponsored by all the nations may be the only way to eradicate it before it spreads throughout the region.

Similarly, it is important for each country to know when a biological control (such as a insect, pathogen, or fish) is added to the waters of one or another of the countries, for eventually it may spread to its own waters, and though harmless in the originating nation, across the border it may prove harmful.

Beyond this, it would be valuable for researchers to exchange information periodically on aquatic weed problems and on the successes and failures encountered in dealing with them.

### 2. RESTRICTIONS ON FOREIGN AQUATIC PLANTS

A ban on importing foreign aquatic plants to the region, and actions to restrict the spread of aquatic plants already present, must be imposed.

The water hyacinth experience has demonstrated that the Nile Basin waterways are extremely vulnerable to infestation by alien aquatic vegetation. An innocuous plant in its South American homeland, the water hyacinth now drains the treasuries of Egypt, Sudan, and Zaire of large sums, which they can ill afford. The toll in human suffering, resulting from disease and the interference with navigation and fishing which the spread of the weed causes, is enormous.

There are equally devastating plants that have not yet reached the Nile Basin. Some examples are

*Egeria densa*
*Elodea canadensis*
*Hydrilla verticillata*
*Lagarosiphon major*
*Myriophyllum spicatum*
*Salvinia molesta.*

The workshop recommends that all nations of the region institute extreme measure to protect against the introduction of all foreign aquatic vegetation. All importation of aquatic plants should be banned unless it is shown by long-term quarantine that they will not prove harmful to the region's waterways.

Included within such a ban should be dealers in fish for aquaria; they commonly introduce new plants for sale to their customers. Botanical gardens that wish to exhibit imported aquatic plants should also be included in the ban. It is also unwise to import aquatic plants for scientific study unless exhaustive tests are first conducted under strick quarantine.

Not only is it important to ban new aquatic plants, but great care must be taken to prevent spreading of individual aquatic weeds to parts of the region now free of them. Some potentially serious weeds now occur as minor infections in waters that do not encourage their full potential. Two of these are *Trapa natans* and *Ceratophyllum demersum,* serious canal weeds now found to a slight extent in the White Nile.

## 3. CONTINUATION OF CURRENT SPRAYING PROGRAMS

To handle the water hyacinth problem in the Nile Basin is a formidable task. Water hyacinth is perhaps the most productive and successful plant on earth. Spread out over thousands of square miles of the Nile Basin in remote areas where transportation is difficult makes it near impossible to design control programs that can entirely eliminate the problem. The visiting workshop participants have the utmost respect for the Government and scientists of the Sudan and their Federal German Republic and Egyptian colleagues for the way they have held the hyacinth at bay and for the way they have kept it from the Gezira, the Blue Nile, the Lower Nile, and Lake Nubia.

In none of the 52 nations where water hyacinth has been declared a weed has it ever been eradicated; keeping it under control is the most that can be hoped for in the near future.

This report identifies a number of alternative techniques to Sudan's current method, 2, 4-D herbicide spraying; however, they all should be considered as adjuncts to the existing program, and in no way as substitutes for it. Herbicides are the only technique today that can be relied upon to clear water hyacinth from waterways.

But although herbicides work, they have serious disadvantages, especially if used over decades. They never eradicate all the plants, and their use becomes a never-ending process; the spray can drift to valuable neighboring crops and destroy them; they are expensive and must be purchased with foreign exchange; they can have an adverse effect on animal life in and around the waterways.

Thus, although the splendid current program must be continued at full capacity, experimentation on the alternatives described in this report must also be carried out as a matter of priority so that successful methods can be used to reduce long-term dependence on herbicides.

## 4. INTRODUCTION OF INSECTS FOR TESTING

The Government of the United States has invested six years of research effort by a team of entomologists in the selection of insects that live on, and destroy, water hyacinth. Initially, the team spent several years in Argentina where water hyacinth has existed for thousands of years without becoming a serious pest. Insects were collected from Argentina's water hyacinth and exhaustively screened in the hope that one would prove so specific to water hyacinth that it could not survive on any other plant. Two insects with this characteristic were found. Transported to the United States, these have been thoroughly screened again--for the United States has had many deleterious insects inadvertently introduced. The results continued to show promise, and one of the insects, the water hyacinth weevil *Neochatina eichhorniae* was released onto water hyacinth in Florida in 1972. This weevil lays its eggs only on the leaves and petiole (leaf stem) of the plant. When the larvae emerge they tunnel down the leaf stem until they reach the heart (rhizome) of the plant. Pupation occurs underwater on the water hyacinth roots, and a cocoon is formed from cut pieces of the water hyacinth's hairlike roots.

The effect of the adult eating the leaves, the larva tunnelling through the petiole and rhizome, and the pupa cutting up the roots is to weaken the water hyacinth plant. Some plants die and sink; more often they survive but have so little vigour that they cannot reproduce, and the hyacinth patch is therefore held in check. Furthermore, the wounds caused by the insect encourage fungus and bacterial rot, as well as invasion by other insects, further weakening the plant. Though the weevil is so damaging to the water hyacinth, it cannot complete its life cycle on any other plant. If the hyacinth is eradicated, the weevil dies and leaves no progeny. Still further, the adult weevil will feed on practically no other plant if water hyacinth is available; only when faced with starvation will it consider another plant. The safety of the water hyacinth weevil is well-documented, and there is virtually no likelihood that in the Nile Basin it could damage any other plant but water hyacinth. The workshop recommends that specimens of Neochatina eichhorniae be introduced to the Sudan and to

Egypt. All standard precautions and quarantine must be followed. In quarantine the weevil should be put through exhaustive tests using commercially important plants of the region to determine if it offers any hazards. If, as seems likely, it passes the tests, government approval and small-scale release--and finally large-scale release--would be warranted.

## 5. ENERGY FROM WATER HYACINTH

Today the nations of the Nile Basin must spend increasing amounts of their scarce foreign exchange to purchase fuel. Yet if development is to proceed, increasing amounts of energy are required.

Over the past three years, the United States' National Aeronautic and Space Administration (NASA), the agency that directs the space program, has found that chopped water hyacinth can be fermented in a sealed tank to produce biogas containing a high percentage of methane. Methane, which is a major component of "natural gas," is similar to petroleum in releasing heat on combustion, and it can be used as a fuel for heating, cooking, and even for running internal combustion engines. Many villages in India have small generators that ferment animal manure and produce "biogas," which is mostly methane, for cooking. A farmer in England has become famous by fermenting his pig manure and pumping the gas into a tank to run his automobile. It is rumored that some of the taxicabs in London are now running on biogas from waste fermentation.

For the Sudan, with its vast resources of water hyacinth (and other plant residues such as cotton stalks), the NASA discovery that biogas can be generated from the plant is most important. Small-scale studies with water hyacinth and cotton stalks should be initiated for biogas production.

Although the NASA program is still in the pilot stage and will not be scaled up to large production for several years, small-scale production of biogas from water hyacinth and cotton stalks could begin immediately in the Sudan. This process also has the advantage that fertilizer is a by-product of the reaction and that there are no major environmental problems that could result from the production of the gas, since its combustion leads to carbon dioxide and water.

The workshop recommends that small biogas generators be built, that a water hyacinth and cotton stalk fermentation study be started, and that tests leading to the exploitation of the resource be begun.

It is an advantage of this method that the high moisture content of the water hyacinth is not a detriment. The fermentation process requires much moisture, and chopped water hyacinth can be used directly without dewatering.

Water hyacinth in dried form could also be used together with dried animal excreta for making open fires intended for repelling wild animals and insects in the Upper Nile Province. In this way water hyacinth will replace wood, thus leading to forest conservation.

The workshop recommends that the authorities encourage the people to burn dried water hyacinth instead of wood as often as possible.

## 6. ANIMAL FEED

Water hyacinth contains all the nutrients necessary for animal growth but making animal feed from it is not easy. Forms of the plant with little leaf and stem (petiole) and large roots are not satisfactory. The best current knowledge suggests that for animal feed the tall-leafed, short-rooted type, generally found in the warmest waters and in waters containing high levels of nutrient, is necessary for adequate nutrition. The reason for this is that the central core of the plant and the roots contain little of nutritive value, and the roots can collect much silt making the feed too high in minerals. Though cattle, water buffalo (Bubalis bubalis) and other ruminants will graze on water hyacinth leaves, some processing is necessary to make animal feed on a large scale. First, the enormous preponderance of water in the plant must be reduced and then the products must be converted into a form that can be stored. Research must be directed to find the best practical form in which water hyacinth could be fed to the various types of ruminant.

To reduce the water content a mechanical device is helpful (sun drying to make hay is slow and rotting may occur). Several presses have been designed to squeeze the water out. The one most favored currently is a screw press. Small simple presses have been designed, which could be built in countries of the Nile Basin.

The pressed product still contains much moisture, but it is in a form more suitable for sundrying, to make hay for example. In the United States researchers have had much success in converting it into silage. In this simple process the pressed water hyacinth is loaded into an airtight container (a silo, or a pit in the ground covered with soil) together with a small amount of carbohydrate (starch, sugar industry wastes, etc,) and left to ferment for about 20 days. The product is equivalent in nutritive value to the grass silages fed by American farmers to their cattle during the winter months.

More than 50 tons of silage have already been made from pressed water hyacinth in the United States. It has proved highly palatable to cattle, promotes weight gain when properly supplemented, and no ill effects have been observed from its use.

The workshop recommends that engineering companies or engineering students build simple presses based on the U.S. designs* and that animal scientists work with ensiling the pressed water hyacinth to test local carbohydrate additives to discover the best combinations for silage to be fed to ruminants.

---

* Contact Professor Larry O. Bagnall, Department of Agricultural Engineering, University of Florida, Gainesville, Florida 32611, U.S.A.

## 7. SOIL ADDITIVES

Under simple controlled conditions the aerobic fermentation of water hyacinth produces a black soil-like compost rich in plant nutrients. Not only does it make excellent fertilizer but it gives heavy clay soils a lighter texture and to sandy soils it adds organic matter and improves water-holding capacity. Water hyacinth compost offers great promise for use in vegetable farming along the river banks in Upper Nile Province and in the Nile Delta region of Egypt. It also may prove extremely valuable in sandy soils in the region. Before it is used north of the Jebel Aulia stringent tests will have to be made to ensure that the composting methods used leave no viable hyacinth seeds. The heat generated in a compost pile will kill bacteria and seeds; however, the danger of infecting the Gezira, Blue Nile, and lower Nile is so great that completely reliable composting methods will have to be designed.

The workshop recommends that water hyacinth composting trials be undertaken south of the Jebel Aulia Dam and that comparative trials between the compost and the manures now used by farmers be instituted. Technical assistance can be obtained from the Government of Sri Lanka. The director of the Home Garden Unit of the Department of Agriculture has devised simple water hyacinth composting methods. The product is now used to produce seedlings for Ceylonese city dwellers to grow their own vegetables.

The Department of Horticulture, Faculty of Agriculture, University of Khartoum, has shown at Shambat that dried water hyacinth makes excellent soil mulch. Spread on the surface of the soil it greatly reduces the loss of soil moisture by evaporation and smothers weeds. It also keeps the soil warm during cool nights and thus speeds the rate of plant growth.

The workshop recommends trials using water hyacinth mulch on vegetable gardens and crops (again south of the Jebel Aulia Dam).

## 8. HERBIVOROUS FISH

Many countries, especially those in Asia and Europe, are beginning to use the grass carp *Ctenopharyngodon idella* to clear submersed weeds from canals. This fish converts the weeds directly into highly nutritious and palatable food; its flesh is ranked among the best-tasting in the United States. After the first few weeks of life the grass carp eats only plants, the submersed weeds of the type that are so troublesome in canals in the Gezira and Egypt.

Large grass carp can weigh as much as 30 kg, and eat several times their weight of weeds each day. Thus, they are a very efficient method for cleaning canal weeds. They will nibble on water hyacinth but affect the plant little. In the State of Arkansas, whose waters were formerly 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.

Far-sighted scientists in both the Sudan and Egypt have introduced fingerlings of this fish. The workshop endorses this and recommends that trials be undertaken rapidly leading to releasing the fish into appropriate canals.

Trials are needed to determine if the canals contain predators that will kill any grass carp released and also to determine if the grass carp will reproduce and itself become a pest. All available information suggests that this is unlikely. The fish comes from cold regions in Northern China and Siberia and to reproduce requires special water conditions that are not likely to be met in this part of the world. It can, however, be artificially spawned locally.

## 9. WATER BUFFALO

Recent experiments in the United States indicate that the water buffalo (Bubalis bubalis--the domestic Asian buffalo that is a major animal resource in Egypt but has not yet been introduced elsewhere in Africa) will consume large quantities of water hyacinth leaves if carefully managed. The buffalo prefers terrestrial grasses but if a fence or herder is used to keep them in the weeds, they will consume them vigorously. Unlike cattle, the buffalo can close its nostrils and has no hesitation in taking to the water or even ducking underwater to get submersed weeds.

A number of animal scientists now believe that the water buffalo is the most neglected and under-appreciated domestic animal in the world. There are numerous indications that on poor forage it can outperform cattle by producing more meat and milk. In one test in Australia a panel was fed meat from water buffalo, from hereford, and Angus cattle (the two cattle being the major beef cattle breeds), all of which had been reared under identical conditions. From all the cuts of meat buffalo steaks were the panel's first and second choices. In Brazil's Amazon basin 40 water buffalo were introduced a few decades ago. Today there are over 200,000 and they have proved far more productive and disease-free than cattle. Papua New Guinea has had a similar experience, and some animal scientists in the United States believe that the animal will become a very important meat source in subtropical southern states.

Sudan's Malakal region appears to be ideal water buffalo territory. The temperature, the abundance of aquatic and semi-aquatic forage that is not being grazed by cattle, and the presence of the rivers (water buffalo like to wallow and cool themselves in water) all seem suited to the animal. The workshop recommends that a small herd of water buffalo be introduced from Egypt (and later, perhaps, a small herd of the swamp variety that is found in Southeast Asia) for trials.

If adopted, water buffalo also could provide farmers in the Malakal area with a source of power for ploughing the soil, pumping water, and pulling carts.

## 10. GEESE

A U.S. animal scientist* in one experiment has found that White Chinese Geese can clear aquatic weeds from waterways with remarkable effectiveness. In

---

* Professor Ernest Ross, Department of Animal Science, University of Hawaii, Honolulu, Hawaii 96822, U.S.A.

doing so, they produce a most delectable and valuable meat as well as eggs. Thus, using geese can turn weeds to a profit and can contribute to improved nutrition.

In the experiment, 65 goslings grew to full size and in 2 years entirely cleared a 2 1/2 acre pond of grassy weeds that were over 6 feet high. To keep the geese healthy small amounts of grain were used to supplement the vegetation diet.

Egyptian participants reported to the workshop that many villagers in their country maintain small flocks of geese, and few, if any, aquatic weed problems are found in the vicinity of such flocks.

The workshop recommends that the potential for using geese for aquatic weed control be studied by poultry scientists and research institutions in the Sudan.

Geese may not make a major impact on the nation's vast aquatic weed problem and they may not be at all useful in the hyacinth infestations in the Nile. Yet in Gezira canals and in haffirs choked with submersed weeds their use may become a very economic way to turn a pest into nutritious food.

In the Gezira a further benefit may occur. It has been reported in the scientific literature that geese can remove weeds from cotton fields. The birds are herded through the fields once the cotton is a few inches high. At this point they will not touch the cotton but they will consume succulent young weed seedlings which emerge from the soil. This too is worth testing under Sudanese conditions. The method was not adopted when it was first reported several decades ago because cheap herbicides were available and they were more convenient to use; however, today geese might save Sudan some of the foreign exchange now spent on herbicides.

## 11. AQUATIC WEEDS THAT CONTROL BILHARZIA

A number of years ago a U.S. research worker* reported in a medical journal** the surprising fact that some aquatic weeds can consume the miracidia and cercariae of bilharzia. The weeds were species of Utricularia, commonly known as bladderwort, carnivorous plants with small bladders that trap small organisms such as mosquito larvae and digest them as food.

The researcher came to this conclusion after noting that some Caribbean islands had no bilharzia while neighboring islands were seriously affected. He found that the "clean" islands had abundant Utricularia species; the others did

---

* Dr. Kenneth S. Warren, Case Western Reserve University Medical School, Cleveland, Ohio 44106, U.S.A.

** M. Gibson and K.S. Warren, Capture of Schistosoma mansoni Miracidia and Cercariae by Carnivorous Aquatic Vascular Plants of the Genus Utricularia, Bulletin of the World Health Organization, 42, 833-835 (1970).

not. Later in the laboratory he was able to show that bladderworts are extremely effective scavengers of bilharzia cercariae and miracidia.

This finding might prove to be important for controlling bilharzia in irrigation canals in the Gezira and in Egypt. Follow-up research to learn more of the Utricularia's potential for this is recommended. Some Utricularia species already can be found in both Egypt and the Sudan.

## 12. PROCESSING WATER HYACINTH LEAVES INTO HUMAN FOOD

An Ethiopian student working at the University of Florida recently discovered that the leaf of certain water hyacinth plants can be converted into a product that is high in crude protein, from 25 to 29 percent. His method is straightforward--not an extraction of the protein, but simple drying in an oven followed by grinding. The product is a light green powder with a slightly spicy smell and a taste similar to tea. Though seldom used in food, it is believed (from extensive research on making feeds for animals from water hyacinth, Chapter V) to be non-toxic. Its potential food uses are as a condiment, as a cooking additive, or as a protein-rich diet supplement.

The secret for getting this palatable, high-protein product is to use only water hyacinth plants with elongated petioles, and only to pluck off the flat green lamina (leaf) portion for making the product.

The workshop recommends that nutrition laboratories in the Nile Basin undertake cautious exploratory work to investigate the nutritional value and utilization of this product. Help and advice are offered by Dr. Berhane Kiflewahid and Professor James Hentges, Department of Animal Science, University of Florida, Gainesville, Florida 32611, U.S.A.

## 13. "UNDERWATER LAWNS"

Three species of spikerushes (*Eleocharis coloradoensis*, *E. acicularis* and *E. parvula*) have been found to out-compete rooted submersed aquatic weeds. The plants grow very close together, are never more than three inches high, and look like an underwater lawn. They crown out and displace neighboring aquatic weeds and prevent the weeds from reentering an area where the "lawn" has been established. The tall problem weeds that block the canal are thus eliminated for good.

Although some canals in the Nile Basin are turbid, and one of the requirements for successful establishment of the spikerushes is adequate light penetration, it is likely that many waters are clear enough for spikerushes to flourish.

The workshop recommends that seeds or propagules* of the three species of spikerushes be brought into the Sudan and a study be made of their potential to displace harmful canal weeds. The investigations should be conducted under quarantine conditions.

All three species are native to California, but none has proved to be a pest. They are found in canals leading to rice fields, but have not become weeds in the fields. This possibility must be explored.

The real potential of this method is for use in Gezira and Egypt in irrigation canals infested with submersed weeds.

## 14. SEWAGE TREATMENT

Roots of land plants extract nutrients from the soil; roots of water hyacinth extract nutrients from the water in which the plants are floating. Sewage is loaded with nitrogen, potassium, and phosphorus, the major ingredients of fertilizer; water hyacinth extracts these very efficiently. It therefore is a potential source for fertilizer ingredients; a source that is within the country's borders and does not require importation or foreign exchange.

In the United States it has been found that a lagoon with 8 to 10 acres of water hyacinth can clean up the sewage wastes of 6,000 people.

The workshop does not recommend that the Sudan use this sewage treatment method because the only sewage facility is at Khartoum and is north of the Jebel Aulia Dam. The chances of infecting the water-hyacinth-clear Nile and Blue Nile waters aretoo great. But in Egyptian towns and cities that have (or plan to have) sewage lagoon facilities, the hyacinth method offers very important benefits. As the lagoon fills with hyacinth the plants are harvested. This gives a continuous treatment and a continuous supply of vegetation with high crude protein content for use in fertilizer, animal feed, compost, biogas generation.

## 15. PROTECTING BIOLOGICAL CONTROL ORGANISMS FROM PESTICIDE RESIDUES

The workshop has developed suggestions for using herbivorous fish to clear canal weeds in irrigation schemes such as the Gezira. These fish show much promise for cleaning the canals cheaply without adversely affecting the environment. Eventually they may be able to be harvested for their very fine and nutritious meat.

---

* Available from Dr. Richard R. Yeo, U.S. Department of Agriculture, Department of Botany, University of California, David, California 95616, U.S.A.

However, the health and survival of fish or other biological agent may be jeopardized by indiscriminant application of pesticides. Insecticides, fungicides, herbicides, and molluscicides alone or in combination have a high chance of killing the organism.

The workshop recommends that when biological aquatic weed control agents are added to the canals, the Gezira Board, the Ministry of Health, and the Ministry of Agriculture work together to ameliorate the effects of pesticide residues on the biological control organisms, as well as to develop application techniques and operating procedures that will protect the organisms from harm.

## 16. THE BASIC BIOLOGY AND ECOLOGY OF AQUATIC WEEDS

An attempt to control aquatic weeds will be made more effective and efficient if a basic knowledge of the weeds and their environment is known in detail. For example, it is important to study changes in their distribution under the effects of current, wind, water level, and season so that the major infestations can be found and treated with a minimum of wasted effort. It is important that researchers and trained technicians continually monitor aquatic habitats throughout the region. In this way, newly arrived plants will be discovered early and can be dealt with before they reach quantities that are impossible to deal with. Also associated biological agents, i.e., pathogens, insects, and other organisms such as turtles will be discovered, some of which may be developed later into biological control agents.

The workshop recommends that appropriate researchers undertake to study the basic biology, ecology, distribution, and taxonomy of aquatic plants throughout the region, and that they work with administrators to use the knowledge gained to support and provide the baseline reference information to maximize the effectiveness of aquatic weed control programs.

# CHAPTER III

## PRINCIPLES OF AQUATIC WEED MANAGEMENT

There are four approaches to the control of aquatic weeds: herbicides, biological methods that use living organisms to attack the weeds, manipulation of the natural environment to harm them, and physical methods that shred the weeds or harvest them from the waterways.

The panel considers that no single method alone will prove adequate; the most lasting aquatic weed management and the most beneficial to the Nile Basin as a whole will be a blend of the different methods in which the benefits of each are maximized and their limitations minimized. For example, harvesting weeds may be satisfactory in accessible waterways, but in remote waters, biological agents or herbicides may be better. In other cases, existing stands may be too dense and woody for a biological agent to be very effective. The best approach may be to attack the stand with herbicides, and use a biological agent only as a follow-up to eliminate the more palatable regrowth.

<u>In general, all aquatic plant control methods complement each other and should not be considered competitive.</u>

When appropriately controlled, aquatic plants can play a vital constructive role in the aquatic environment by

- Producing oxygen;
- Serving as food, nest-building material, and sites for egg attachment for aquatic insects and fish;
- Protecting small organisms from predation;
- Converting silt and dissolved nutrients in the waterway to potentially useable organic matter;
- Serving as food for birds, fish, and land animals; and
- Anchoring soil in place.

Aquatic weed management should maximize and capitalize on the benefits of the plants. Thus, waterway clearing should be conducted so as to leave an amount of plant material appropriate to the needs of fishing, public health, navigation, drainage, vegetation resources, and water purification. These often do not call for eradication. To plan for aquatic plant management of this kind, a scientific team with biologists and specialists in ecology, agronomy, horticulture, engineering animal nutrition, soil science, economics, and systems management may be needed.

Before choosing any weed control method or combination of methods, the first step is to consider ways that decrease the source of the weeds--prevention being much better than cure. Examples of such methods are strict control of the movement of aquatic weeds to ensure that weed-free waters are not infected (weeds are often distributed as fragments caught on boat hulls, as packing for produce and tropical fish, and as ornamental plants for fish ponds) and quarantining or banning the import of foreign aquatic plant species (favorites of tropical-fish fanciers).

This report emphasizes rearing wild or domesticated animals that feed on aquatic vegetation. Agricultural or living patterns that encourage people to raise these animals may also benefit aquatic weed control programs and provide income, food, and improved nutrition at the same time. The approaches recommended, however, may not prove practical or advantageous elsewhere in the world.

## INTEGRATED CONTROL

No matter what control method is being used, it will probably be used concurrently with another control method, often accidentally. In order to ensure that these combinations are used to enhance the overall control effect at the lowest cost and with the least harmful side effects, an integrated approach is needed. Integration of control methods implies intelligent combining and utilization of all controls. This requires attention to compatibility of agents or methods; to economic threshold; to timing of application; and to technique of application.

Advantages of integrated control are obvious. Less chemical may be used when assisted by a biological agent. Likewise, mats of weeds already reduced by biological methods can be brought below the economic threshold by judicious herbicide application. There is a saving in energy when using mechanical harvesters with biological agents and enhanced control when using combinations of biological agents.

Examples of current research in integrated control include the following:

- Destruction of aquatic weed species with a herbicide as a preparation for displacement by beneficial competing plant species.
- Combinations of biological agents (grass carp and water hyacinth weevils, water hyacinth mite and water hyacinth weevils, water hyacinth weevils and zonate leaf spot fungus).
- Combinations of herbicides and water hyacinth weevils.

Results of these studies are still preliminary; recommendations for an integrated control program against water hyacinth are scheduled to be ready in 1978.

# CHAPTER IV

## WATER HYACINTH AS A SOURCE OF ENERGY

### BIOCONVERSION

One promising solution for generating an abundance of inexpensive energy appears to be the bioconversion of water hyacinth by microbial anaerobic fermentation to biogas containing a high percentage of methane. When organic material decays it yields useful by-products. The kinds of by-products depends on the conditions under which decay takes place. Decay can be aerobic (in the presence of oxygen) or anaerobic (in the absence of oxygen). Methane gas and carbon dioxide are produced when organic material such as water hyacinth is decomposed by putting it into air-tight containers or dirt trenches covered with insulating materials such as plastic and soil. When organic material is anaerobically digested, carbon is utilized for energy and the nitrogen for building cell structures. The bacteria use up carbon about 30 times faster than they use nitrogen. Water hyacinth not only has a very favorable carbon to nitrogen (C/N) ratio normally, but also contains a desirable solid to water ratio in the plant tissue, allowing the wet harvested plants to be fermented directly without the addition of more water except in a small starter solution.

At a temperature range of 75 - 105° F water hyacinth should be completely digested in 70 days producing from 4 - 6 cubic feet of biogas (per lb of dry material) containing approximately 65 percent methane with a fuel value of 500 - 700 BTU/$ft^3$(1, 2). Fermentation can also take place at temperatures up to 140° F. A desirable fertilizer is produced as a by-product from anaerobic decomposition; however the reaction at 140° F produces a fertilizer sludge product of lower quality.

An abundant supply of water hyacinth can be found in the Nile River. Harvesting these plants for the purpose of generating biogas would provide an additional bonus in opening up impassible portions of the Nile to navigation. The year-round temperature in the Sudan is such that the conversion of water hyacinth to biogas utilizing individual small units or very large systems could probably be carried out without additional energy requirements.

Throughout India small fermentation units utilize cattle manure for anaerobic fermentation. These units consist of simple, one-stage containers filled with animal waste. The biogas evolved during the fermentation process is collected over water in chambers as simple as two oil drum containers. One barrel is placed upside down in the second barrel and both filled with water. The biogas fills the inner barrel and causes it to rise as the biogas evolves. This simple system can also be applied to the anaerobic fermentation of water hyacinth. Whole, Green water hyacinth can be deposited in large trenches sealed with soil and allowed to ferment. The biogas can then be used directly or collected for storage in containers described above.

## COMBUSTIBLE MATERIAL

One other potential source of energy derived from water hyacinth is heat from burning compressed "logs" made of dry water hyacinth. This fuel might be satisfactory for cooking purposes as well as useful for a natural insect repellent at night. The dry hot climate in the Sudan, unlike humid areas such as Florida, any allow for sun drying of water hyacinth without requiring additional energy.

## RECOMMENDATIONS

### Bioconversion of Water Hyacinth

1. Preliminary tests can easily be initiated to evaluate the practical feasibility of anaerobically fermenting water hyacinth in large trenches sealed with soil and vented at regular intervals to tap the biogas containing approximately 65 percent methane that is evolved in this natural process. Information can be collected on soil porosity, soil temperature, and length of time required under these conditions. Evaluation of the resulting fertilizer in the form of sludge can also be conducted subsequent to these fermentation experiments.

2. Long range studies should be initiated for producing biogas from water hyacinth in more sophisticated systems such as those needed to produce large quantities of biogas for a city. Such studies should look at both single batch systems and continuous feed systems.

3. Other aquatic plants should be studied as potential candidates for bioconversion into methane. Certain terrestrial plants such as the stalks from cotton plants should also be investigated for their potential use in this area.

### Combustible Material

1. Characteristics of processed and whole dried water hyacinth as fuel should be determined, including factors such as combustibility, heat content, combustion efficiency, and effect of moisture content.

2. Practical methods should be devised for use of dried water hyacinth as cooking, heating, and insect- and predator-repelling fuel and people living near sources of water hyacinth should be instructed and encouraged to use them.

## LIMITATIONS

Fermenting aquatic weeds to methane can be accomplished without dewatering, but the weeds usually have to be chopped and crushed to make them more available for bacterial attack. Though simple, cheap equipment can be used for fermentation chambers, they must be constructed and maintained with care. Methane-producing bacteria cannot survive if oxygen is present in the culture medium. Air that is introduced when the chamber is loaded with weeds causes a lag before anaerobic digestion can begin. During this lag, which can be up to 10 days, the oxygen is used up by aerobic bacteria, which produce carbon dioxide, not methane. With the oxygen gone, anaerobic bacteria take over, but biogas always contains a substantial amount of carbon dioxide, which, being nonflammable, dilutes the heating value of the methane.

Biogas production is not fast. The bacteria must be given time; 10 - 60 days may be needed. Furthermore, the initial start-up is slow because the bacteria take time to build up a population big enough to ferment the weeds.

Experience with present biogas generators (using animal, human and vegetable wastes) has shown that the bacteria are sensitive and easily "upset." It takes skill and continual supervision to maintain methane production. The following factors must be considered:

### Temperature

Maximum production occurs at 32 - 36°C. In temperate regions some heating may be needed, but generally in climates that foster aquatic weed growth these temperatures can be reached, especially if the digester is in the sun. The temperature must be kept relatively constant--large fluctuations distress the bacteria.

### Nutrients

The feedstock must contain adequate nitrogen for bacterial growth. The relative amount of carbon present should not exceed 30 times the amount of nitrogen. Carbon to nitrogen ratios between 20:1 and 30:1 are best. Luckily, most aquatic weeds are in this range.

### Mixing

For maximum gas production, the ferment must be stirred or agitated at least twice daily to break up surface scum.

Acidity

During digestion, acids can accumulate and suppress the bacteria; lime or other alkali may be needed to neutralize them.

Biogas must be handled carefully: methane mixed with air is explosive.

So far no assessments of economic feasibility of using aquatic weeds in a biogas generator have been relevant to developing-country situations.

## REFERENCES

1. B. C. Wolverton, R. C. McDonald, and J. Gordon. Bioconversion of water hyacinth into methane gas: Part 1. NASA Technical Memorandum TM-X-72725 (1975).

2. J. R. Miner, J. W. Wooten, and J. D. Dodd. Water hyacinth to further treat anaerobic lagoon effluent. Amer. Soc. Agr. Eng. Proc. 271, 170-173 (1971).

## CHAPTER V

## FEED FOR ANIMALS

The Nile River presents unique opportunities for the utilization of aquatic plants, especially water hyacinth (Eichhornia crassipes) in animal diets.

-- A large population of ruminant animals (cattle, buffalo, sheep, goats) in the vicinity of the Nile River is subject to food shortages during the dry season. It has been demonstrated that water hyacinth, some submerged plants, and some semi-aquatic plants have nutritive value in animal diets.

-- A large supply of harvested water hyacinth will be available from the Nile River when mechanical harvesting begins around cities, dams and in the vicinity of crops or gardens where chemical control by spraying is prohibited. Harvested water hyacinth has been processed and stored as silage and dried animal feeds.

-- During annual dry seasons when land forage is scarce, water hyacinth leaves and semi-aquatic plant parts such as cattail shoots (Typha spp.) can be grazed or hand fed to ruminant animals in need of protein, cellulosic energy and nutrient minerals. An abundance of these forages exists along the White Nile.

The utility of aquatic plants for animal feeds has been evaluated by:

- Chemical analysis;
- Acceptability in diets of animals; and
- Digestion trials with livestock.

### PREPARATION FOR FEEDING

To capitilize on the huge quantities of aquatic weeds that occur in many countries, various methods of preparing them for livestock diets will have to be used. Their high moisture content and bulkiness makes them expensive and cumbersome to transport; consequently, they must be partially dewatered or dried and processed into manageable products for animal feeding. Several approaches to preparing them as feedstuffs are possible.

Weeds chopped and partially dewatered by pressing can be fed directly to livestock. Surprisingly, this has seldom been tried in developing countries. It seems likely that cattle, water buffalo, goats, sheep, donkeys and swine could utilize partially dewatered aquatic weeds in their diets when forage or other nourishment is not readily available. This is particularly likely during dry seasons in countries such as the Sudan.

Whole, chopped, or partially dewatered weeds can be sun dried to hay. Rapid spoilage makes this difficult to do under natural conditions in the humid tropics, but it may be a promising technique under arid, artificial, or other more favorable conditions.

Dewatered weeds can be dried with heated air and processed into dry, stable products, meal, or pellets, that can be stored without molding. This energy-intensive method is likely to be of little value in developing countries, unless cheap, useable energy, e.g. solar energy, is available.

Aquatic weeds can be ensiled (Loosli et. al., 1954). In the ensiling process, the weeds are preserved by organic acids produced during fermentation. When the weeds are placed in a silo, respiration of plant cells continues until oxygen is exhausted then naturally occurring bacteria ferment the plant components, producing lactic and other organic acids. This process takes about 20 days. Water hyacinth press residue has been shown in extensive experiments in Florida (Baldwin, Hentges and Bagnall, 1974; Baldwin, Hentges, Bagnall and Shirley, 1975) to produce a palatable, digestible, and nutritious silage that is readily accepted by cattle and sheep. The first large-scale production of water hyacinth silage occurred in Florida in 1972. Silage was made in small-barrel (55 gallon) silos, in a full-sized tower silo and in stacks. No fundamental problems were encountered. Harvested water hyacinth plants proved to have exceptional water-retention properties that were favorable for handling, transport, and storage of press residue without seepage. Also, these properties allowed the making of silage from water hyacinth with a higher moisture content (80 - 90 percent) than is found in most land forage plants (70 - 80 percent). The nutritive value of a host of dried and ensiled aquatic plants other than water hyacinth has been reported by Linn et. al., 1975.

Ensiling may be particularly important in tropical and subtropical regions where a high relative humidity and frequent rains make it difficult to dry forage naturally as hay. Because silage is bulky (small weight/volume), silos must be located adjacent to the vegetation supply and, if possible, to the market or feeding facility. Stack or tower silos can be built on most farm sites regardless of the level of the water table. Another advantageous location for silos may be near sewage or industrial waste lagoons where water hyacinth, duckweed, or other aquatic plant crops might be grown to remove pollutants from waste water.

Aquatic weeds can be preserved as silage in stack silos using organic acid preservatives. Propionic, acetic, and formic acids applied under carefully supervised conditions at rates of about 1/2 gallon per ton of chopped pressed water hyacinth have produced good-quality silage. The acids inhibited undesirable bacteria and molds and kept the fermentation temperature within a desired range. Acid-preserved silages were readily accepted by cattle and sheep (Byron, Hentges, O'Connell and Bagnall, 1975).

## NUTRITIONAL POTENTIAL

### Chemical Analyses

Concentrations of 10 nutrient inorganic elements for livestock were determined in water hyacinth, hydrilla, hornwort, pondweed, eelgrass and naiad at monthly intervals over a period of a year (Easley and Shirley, 1974). On a dry weight basis, phosphorus, magnesium, copper, zinc, and manganese were in the range of concentration of land forages in the United States; exceeding that range was sodium by 10 - 100 times, iron by 4 - 19 times, and potassium by 2 - 3 times. Calcium concentration was higher and phosphorus generally lower. The Ca:P ratio in water hyacinth was satisfactory for cattle. Hydrilla, naiad, hornwort, pondweed, and eelgrass had average Ca:P ratios of approximately 30 - 90:1, and one kg. of these dried plants would provide 3 - 6 times the daily calcium requirement of a cow on a maintenance ration.

The leafy parts of floating aquatic plants, such as duckweed and water hyacinth from nutrient enriched waste water, usually contain 25 - 35 percent crude protein on a dry weight basis. Whole plant water hyacinth grown on waste water average about 20 percent crude protein, but this drops to about 14 percent after dewatering and processing into a dried product. A study in the Sudan (Osman, El Hag and Osman, 1975) on mature, small water hyacinth showed a mean crude protein content of 11.5 percent in the lamina (leaf) and 8.2 percent in the shoot (aerial part). Protein in the lamina was more digestible and was voluntarily consumed in larger quantities by sheep. This study clearly showed the inadequacy of water hyacinth alone as a diet for sheep. Supplementing chopped water hyacinth shoots with dura grain, cottonseed cake, and hay markedly improved performance. The energy-yielding components of whole-plant water hyacinth are predominantly cellulose and hemicelluloses. The indigestible lignin content is significant and mostly concentrated in the submerged part.

### Feeding Value

Animal performance has been best when processed water hyacinth made up less than 33 percent of the diet on a dry organic matter basis. The absorption and net retention of nutrient mineral elements in floating (water hyacinth) and submerged (Hydrilla supp.) aquatic plants was satisfactory when these plants made up 33 percent of the dietary organic matter for cattle and sheep (Stephens, Easley, Shirley and Hentges, 1972).

Digestion of organic matter of various parts of water hyacinth plants by cattle rumen microbes was decreased by partial dewatering and processing. The organic-matter digestibility of the fresh unprocessed whole plant, leaf, petiole, and submerged parts was 55.7, 50.8, 58.7, and 51.2 percent, respectively. Corresponding values after pressing out the water at 50 psi and air-drying at 60°C were 26.3, 41.0, 50.8, and 44.2 percent, respectively (Kiflewahid, 1975). Although losses occurred in processing, these values indicated satisfactory organic matter (energy) utilization in processed water hyacinth whole plant and plant parts when fed to livestock as the roughage portion of their diet.

Fibrous aquatic plants such as water hyacinth can substitute for some dietary crude fiber (roughage) sources such as cottonseed hulls, sugarcane bagasse and hays in ruminant animal diets.

The provitamin A carotenoids and pigment-supplying xanthophyll are generally as high as or higher than in land forages such as alfalfa.

## PLANT JUICE PROTEIN - PIGMENT CONCENTRATES

It has long been known that the juices pressed from green plants contain part of the plant protein. This protein can be separated from the juice liquid by heat, followed by flotation or settling; precipitation by pH adjustment, either by addition of acid or by fermentation; or in some cases simply by allowing the juice solids to self-precipitate and settle to the bottom. Protein concentrates thus obtained from land plants tend to have a protein concentration slightly greater than double that of the original vegetation and a fiber content less than one percent. Thus they have the potential for use in the rations of monogastric animals such as swine or poultry, or in human diets.

In addition to their protein content, such juice concentrates may contain useful pigmenting agents such as xanthophylls which are used in the poultry industry to color egg yolks and skin. While alfalfa has been an important source of xanthophylls, concentrations of it in such aquatic plants as Eurasian watermilfoil may be 2 1/2 - 3 times those of alfalfa. An aggressive pressing operation will cause approximately two thirds of these pigments to be in the juice fraction. The subsequent handling of the juice will determine what part of these pigments are recovered in usable form, since they are highly unstable. High-temperature drying of the juice concentrate, for example, causes high losses, due to oxidation. Prolonged storage can also cause high losses.

Production of juice concentrates from aquatic plants is particularly attractive, since the pressing operation serves the dual function of obtaining the juice fraction while reducing the moisture content of the fibrous fraction to a level that may be much more desirable for handling, transport, or ensiling.

The ash content of aquatic plants tends to be higher than that of land plants. At least part of this may be due to mineral encrustations on the surface of the plants. Much of this ash content will find its way into the juice concentration, thus diluting the protein. In the case of Eurasian watermilfoil in Southern Wisconsin (Koegel et. al. 1973; Sy, 1974) a high percentage of the ash content is calcium compounds, which could be of value in certain rations such as those of laying hens. More than half of this calcium can be removed by rinsing the vegetation before pressing, thus indicating that a significant part of it is external to the plants.

Juice protein concentrates, as originally separated, are high in moisture. More than two thirds of this moisture can be removed by drainage followed by a combination of gentle pressing and kneading or reorienting.

Protein concentrates may be used fresh or they may be preserved for later use by dehydration, or by addition of acid to a pH of approximately 3.5.

When juice-protein concentrates are made from unproven plants, bio-assays should be made to determine biological value and whether toxic substances are present at significant levels.

## LIMITATIONS

Extremely high concentrations of water in aquatic plants make handling and storage as feedstuffs impossible without partial dewatering or drying.

Apparently, high concentrations of minerals such as iron, calcium, potassium, and manganese limit the consumption of aquatic plants by animals. Since dietary requirements for these elements are provided when aquatic plants are used as approximately 10 - 20 percent of the diet, a mineral imbalance may result if this level is exceeded.

Traces of pesticides have been found in samples of aquatic plants; consequently, they must be tested for pesticide residues before being processed into commercial animal feed. Chemical residues are not likely to cause a problem unless the plants have been chemically treated immediately prior to harvesting.

In canals and waterways excessively polluted with animal waste, a problem might arise due to pathogenic bacteria. Aquatic plants harvested from such waters should be screened for harmful pathogenic bacteria before use in animal diets.

Success in ensiling is dependent on completion of several steps in the fermentation process. The first requirement is to chop the plants into small particles, reduce moisture content, and firmly pack the chopped material into a silo or stack. The second requirement is to achieve a sustained fermentation which produces sufficient organic acids, especially lactic and acetic acids. Aquatic weeds are often low in fermentable carbohydrate content; consequently, preservatives containing nutrients essential for bacterial action must be mixed with aquatic plants as they are placed in a silo. Aquatic weed ensilage with a high moisture content may benefit from the addition of absorbent materials such as dried industrial mill by-products as it goes into a silo. In Florida, dried citrus pulp has been added to water hyacinth press residue as a source of both carbohydrate and absorbent matter. Corn, sorghum (dura), and some by-products of rice, grain, and sugarcane milling industries are all potential preservatives for silages.

## RECOMMENDATIONS

1. Immediate consideration should be given to the utilization of mechanically harvested water hyacinth as silage for feeding to cattle and/or sheep. Research is needed on methods of ensiling aquatic plants with various preservatives and feedstuffs that provide carbohydrates for fermentation and other useful nutrients. Special attention should be given to the ash content of ensilage and its effect on acidity during fermentation.

2. Immediate consideration should be given to the grazing or hand feeding of water hyacinth leaves to cattle and sheep during dry seasons.

3. Immediate consideration should be given to the use of the gentle Asian swamp-type or river-type water buffalo for grazing of marsh grasses, cattail shoots, water hyacinth leaves and other aquatic and semi-aquatic plants. They should not be considered as a replacement for cattle but as an added source of income or wealth. It would probably be necessary to use a battery-operated electric fence and a herder to restrict grazing to an area until the less palatable plants were consumed.

4. Immediate attention should be given to the use of ducks and geese to keep ponds and canals free of aquatic plants. The fowl and their eggs could also be used as food.

5. Long-term nutritional investigations of all potentially useful aquatic plants should be initiated. Priority should be given to floating plants which may be consumed in their natural state, such as duckweed grazed by geese (Culley and Epps, 1973) and water hyacinth leaves grazed by ruminating animals. Studies will be needed to identify potential mineral imbalances and the need for supplemental nutrients with these grazed plants.

6. Likewise, studies on nutrient content and digestibility should accompany any engineering studies to develop superior harvesting and processing methods. Objectives would be minimization of losses of soluble nutrients in discarded press juice and production of highly digestible feedstuffs.

7. Research on identification and quantitative measurement of inorganic minerals in aquatic plants is required so that they can be utilized as sources of supplementary minerals in livestock diets. Additionally, research is needed on the digestion, absorption, and metabolism of these minerals by various species of domestic animals. Further, these measurements should be obtained on parts of the plants, especially the aerial (shoot) and submerged parts, because they may be harvested and marketed separately for different purposes.

8. It is suggested that concentrations of nitrate, cyanide, oxalates, tannins, and dicoumarins be investigated in all plant varieties, in all locations, and in all seasons.

9. Research on the amino acid composition and cell wall content of various species of aquatic plants should be continued (Taylor and Robbins, 1968).

The dietary utilization of these substances should be evaluated with various classes of animals.

10. The amino acid and protein-pigment content of pressed-plant juice should be studied with a view to possible changes with season of the year and fertility of the water in which the plants are grown.

## REFERENCES

1. J. A. Baldwin, J. F. Hentges, Jr. and L. O. Bagnall. Preservation and cattle acceptability of water hyacinth silage. Hyacinth Control J. 12, 79 (1974).

2. J. A. Baldwin, J. F. Hentges, Jr., L. O. Bagnall and R. L. Shirley, Comparison of pangolagrass and water hyacinth silages as diets for sheep. J. Anim. Sci. 40, 968 (1975).

3. H. T. Byron, J. F. Hentges, Jr., J. D. O'Connell and L. O. Bagnall. Organic acid preservation of water hyacinth silage. Hyacinth Control J. 13, 64 (1975).

4. D. D. Culley and E. A. Epps. Use of duckweed for waste treatment and animal feed. J. Water Pollution Control Fed. 45, 337-347. (1973).

5. J. F. Easley and R. L. Shirley. Nutrient elements for livestock in aquatic plants. Hyacinth Control J. 12, 82 (1974).

6. R. G. Koegel, D. F. Livermore, H. D. Bruhn and P. D. Bautz. Improving surface water conditions through control and disposal of aquatic vegetation, phase II. U. Wisc. Water Resources Center Tech. Rpt. WIS-WRC 73-07 (1973).

7. J. G. Linn, E. J. Staba, R. D. Goodrich, J. C. Meiske and D. E. Otterby. Nutritive value of dried or ensiled aquatic plants. I. Chemical composition. J. Anim, Sci. 41, 601-609 (1975).

8. J. G. Linn, R. D. Goodrich, D. E. Otterby, J. C. Meiske and E. J. Staba. Nutritive value of dried or ensiled aquatic plants. II. Digestibility by sheep. J. Anim. Sci. 41, 610-615 (1975).

9. J. K. Loosly, R. P. Belmonte, V. Villegas and E. Cruz. The digestibility of water hyacinth by sheep. The Philippine Agriculturist. 38, 146-148 (1954).

10. H. E. Osman, G. A. El Hag and M. M. Osman. Studies on the nutritive value of water hyacinth. Aquatic Weeds in the Sudan, National Council for Research, Khartoum, Sudan (1975).

11. E. L. Stephens, J. F. Easley, R. L. Shirley and J. F. Hentges, Jr. Availability of nutrient mineral elements and potential toxicants in aquatic

plant diets fed steers. Proc. Soil and Crop Sci. Soc. of Fla. 32, 30 (1972).

12. Se Hiong Sy. Mechanical management of aquatic vegetation: Analytical studies of unit operations potentially useful in the pressing of aquatic vegetation. Ph.D. Dissertation, U. Wisconsin, Madison, Wisconsin (1974).

13. K. G. Taylor and R. C. Robbins. The amino acid composition of water hyacinth and its value as a protein supplement. Hyacinth Control J. 7, 24 (1968).

## CHAPTER VI

## INSECTS AND MITES

Insects have been used to control certain weeds since 1902. Notable successes, in which biological control reduced a weed species below the economic threshold are exemplified by control of cactus in Australia and Hawaii, Klamath weed control in California, U.S.A., and Alligatorweed control in Florida and Louisiana, U.S.A. Alligatorweed is an aquatic weed that could not be controlled by chemical or mechanical means. A small flea battle from Argentina was introduced. Within months it began to reduce alligatorweed to a level where it ceased to be a problem--which gives some hope for success in controlling the aquatic weed, water hyacinth.

Currently, five species of insects and one mite species that are potentially effective and safe are worthy of consideration. These are the mottled water hyacinth weevil, *Neochetina eichhorniae;* the chevroned water hyacinth weevil, *N. bruchi;* the water hyacinth borer, *Acigona infusella;* the moth, *Sameodes albiguttalis;* the water hyacinth grasshooper, *Cornops aquaticum;* and the water hyacinth mite, *Orthogalumna terebrantis.* Each species has its own attributes and limitations in biological control.

Below are some general advantages in using these insects and mite against water hyacinth.

- Once established, the control is permanent.
- The biological agent will attack the weed in areas where it is too inaccessible for use of other control means.
- The biological agent will redistribute some of the nutrients tied up in water hyacinth, eventually allowing them to enter the food chain of other organisms.
- The overall cost in using these control agents is very low as compared with costs of chemical and mechanical controls.
- The biological agent populations increase geometrically, thus being able to keep pace with any increase in the weed population.
- Insects and mites are host-specific and will not survive on other important plant species. If unimportant related species are fed upon to some extent, the insect may still be useable.

## LIMITATIONS

There are, of course, also limitations.

1. Eradication is not possible using a biological agent, nor is there any absolute guarantee that the quantity of the weed will be reduced below the economic threshold.

2. Control using this means is often slow. The biological agents may spread slowly, and the effect on the weed may be slow in reaching its full potential.

3. Some care, knowledge, and skill are needed for the initial release of the insects. If this expertise and precautionary procedures are lacking, a less than optimum population may result. As an example of precautions taken, eggs were collected from imported adults. These eggs were washed in hypochlorite solution and placed in plants distant from the parent insects to assure that pathogens of the parent insects would not be liberated.

4. Quarantine handling is necessary. Usually a quarantine facility is needed for the handling of the first shipment of insects or mites. Sometimes additional quarantine testing on local plant species is needed, but it should not be overly elaborate. Usually, a modified laboratory room, inspected and approved by quarantine officials, can serve as an adequate quarantine facility.

5. Permits for importation and release are needed from the authorities concerned. Sometimes this can be a time-consuming process due to the need for careful interpretation of the results of testing and the need to consult with several different agencies.

## STATUS OF BIOLOGICAL CONTROL AGENTS

At present (November 1975) the five insect species and the mite species have already been considered for introduction into some areas to control water hyacinth. Some of the species have already been introduced, and others have been tested or are being tested. Their status is presented in the table below.

| Species | Tested in Country of Origin | Tested in Quarantine | Released in Field (country) | Tabled |
|---|---|---|---|---|
| *Neochetina eichhorniae* | X | X (U.S.) | Australia, U.S., S. Africa, Indonesia, Fiji | |
| *Neochetina bruchi* | X | X (U.S.) | U.S. | |
| *Acigona infusella* | X | X (U.S.) | | X |
| *Sameodes albiguttalis* | X | X (U.S.) | | |
| *Cornops aquaticum* | X | no | | X |
| *Orthogalumna terebrantis* | X | no | S. Africa, Australia, U.S., Fiji (S. Africa & U.S. releases accidental) | |

## RECOMMENDATIONS

Considering the seriousness of the water hyacinth problem in Sudan and other countries, the following recommendations are made; they proceed stepwise, and should be considered in sequence.

1. Water hyacinth bioceuoses should be examined to determine what natural enemies are already present and their parasites or predators so as to anticipate the possible effect of these on introduced insects or mites. Some of the existing natural enemies may be useful to introduce in other areas of water hyacinth control.

2. A simple but adequate quarantine facility should be established and approved by appropriate quarantine officials.

3. Approval should be obtained from the appropriate office (probably plant quarantine or plant protection) for importation of the particular insect or mite species.

4. A list of test plants, maybe only two or three plants or perhaps a dozen, should be prepared. (It may be none, this eliminating the need for quarantine testing.) Full-scale testing of all plants, however, is not necessary since it is time consuming, requires an excessive quantity of imported insects, and repeats work already done by others. The testing time required in quarantine may be as little as two weeks or as much as two months but should be minimized.

5. Biological control insects should be obtained from a country where they are being used successfully. This helps avoid natural enemies of the beneficial insects and assures a useful strain. Quarantine procedures should still be used in introducing these species, and only the next generation produced by these imported insects should be released in the field.

6. One large field release site should be established to serve as a source of insects for research and for other releases.

## RESEARCH CONTACT

B. David Perkins, Agricultural Research Service, U.S. Department of Agriculture, 3205 SW 70 Avenue, Fort Lauderdale, Florida 33314, U.S.A.

# CHAPTER VII

# HERBIVOROUS FISH

## WHITE AMUR (GRASS CARP)

The white amur or Chinese grass carp (*Ctenopharyngodon idella* Val.) is one of the fast-growing and economic food fish extensively cultured in ponds in China, Japan, and some of the Southeast Asian countries. The fish is herbivorous in its feeding habits; however, water hyacinth is low on its preference list. Most submersed aquatic vegetation is readily eaten.

The white amur offers several advantages. They will reduce the growth of aquatic weeds in the canals of the Gezira scheme (where herbicides cannot be used as the water is used for bathing and drinking purposes). The removal of the weeds will indirectly decrease the vector snails of bilharzia. The fish will clear up the weeds in the haffirs, resulting in better water quality. They are also an excellent source of food for the population. Only 20 to 40 fish per hectare are needed to maintain weed control.

The main problem that could occur with the white amur is the possibility that it would spawn. This is not likely, and it is not known if a problem would result even if it did reproduce. Also, the white amur should be reared to a size sufficient to withstand predation by other fish before they are released.

On January 1, 1975 about 10,000 fingerling white amur were introduced into Sudan from India. The fish are currently restricted to ponds at the Experimental Fish Farm at Shagarra.

Egypt is also testing the white amur.

## TILAPIA

Certain species of tilapia eat large amounts of aquatic vegetation and convert it to good quality fish flesh. Two of these species are *Tilapia zillii* Gerv. and *Tilapia melanopleura* Dum. However, Uganda reports the feeding habits of *T. melanopleura* to be questionable.

Control of aquatic weeds and bilharzia can be combined with fish production. Also, the T. zillii will feed on midge, mosquito larvae, and Nimbridylis acuminata, which the white amur will not eat.

The tilapias often overpopulate, and management techniques such as periodic harvesting or using predator fish must be employed.

Tilapia melanopleura was introduced into the Sudan from Zaire in 1973. Its usefulness in the water has not yet been determined.

## OTHER FISH

It will be advantageous to consider other exotic fish for control of water hyacinth and other aquatic weeds in waters of the Nile Basin including South American silver dollar fish (Metynnis roosevelti Eigenmann and Mylossoma argenteum E. Ahl), common carp (Cyprinus carpio L.), tawes (Barbus gonionotus), and the caven (Maglobramula bramula).

## RECOMMENDATIONS

1. It is recommended that the use of herbivorous fish for controlling aquatic weeds in the Nile Basin be explored. Both native fish (tilapias and others) and exotic fish (white amur and others) should be studied in these countries to the extent of the needs of each country.

2. Studies with the white amur should be continued and the studies expanded in the future.

## CHAPTER VIII

## OTHER BIOLOGICAL CONTROLS

Many organisms are predators, pathogens, or parasites of the water hyacinth. Although they are not yet widely used, the following could one day prove useful for restraining the plant.

### PATHOGENS

Pathogens have been used successfully in Australia to control skeletonweed, *Chondrilla juncea.* Bacteria were instrumental in control of cactus in Australia and Hawaii. Control of water hyacinth using pathogens may be a desirable approach. Pathogens studied in the United States are all native species and include among the most common *Acremonium zonatum* and *Cercospora* spp. They are not yet beyond the research phase, however, and utilization in the field has not become practicable.

Consideration of importing pathogens is not recommended at this time for use against water hyacinth. Research currently underway in other parts of the world may eventually lead to discovery of a useful and safe pathogen, and its importation could possibly be considered at that time.

Several species of pathogens which already exist in Sudan and other countries of Africa may be useable. These include species of fungus belonging to the genera *Helminthosporium, Fusarium,* and *Alternaria.* Research is needed on methods of utilization or application and on host range.

### MANATEE

This large aquatic animal looks somewhat like a dolphin or small whale but it lives in tropical waters. It eats only vegetation, likes submersed weeds of the type found in the Gezira scheme, and will eat large quantities of water hyacinth.

Manatees are found in the coastal waters of all countries along Africa's west coast from Senegal to Angola. They are also reported to be in Chad, Niger, and Mali. But it is in the South American republic of Guyana that manatees have been used most to clear canal weeds. Some of them have maintained weedfree canals for over 15 years without any attention. Unfortunately, manatees are close to extinction and unless researchers can learn how to breed and rear them, they will soon be extinct. An international laboratory for manatee research, now being established in Guyana, plans to learn the secrets of manatee reproduction and husbandry so that these endangered mammals can be saved from extinction.

The manatee's nearest relation, the dugong, is found in Sudanese waters along the Red Sea coast. Dugongs, too, are close to extinction. Sudan should make vigorous efforts to save the dugong because there is a chance that it, too, can be used for clearing canals of weeds. However, the dugong prefers to live in the sea and seldom visits freshwater, whereas the manatee is at home in both. It would be important to learn if dugongs can adapt to freshwater. This could be done by a veterinarian placing a dugong in an experimental tank in which the water was slowly changed from salt to fresh. The experiment should be conducted near Port Sudan so that the animal can be released quickly back to the sea if it becomes stressed.

Should it prove possible to keep dugongs alive and healthy in freshwater, Sudan could cooperate with the International Manatee Research Centre in Guyana and develop the husbandry and breeding of dugongs for weed-control purposes.

## WATER BUFFALO (BUBALIS BUBALIS)

This gentle domestic animal has been the mainstay of agriculture in Asia for 4,000 years. It is not at all related to the wild African buffalo (Syncerus caffer) that is found in the Sudan.

Recently, American researchers have found that, with management, the water buffalo will consume large quantities of water hyacinth leaves. This does not kill the plant but weakens it, stops its reproduction, and opens it to infection by fungi and bacteria that can destroy it. Furthermore, water buffalo will consume many weeds and coarse grasses along river banks. It readily enters the water to gorge and its splayed feet give it more stability than cattle in soft mud. In addition, it can close its nostrils (which cattle cannot) and does not hesitate to get its head wet eating weeds at the water surface or under it.

Little research has been conducted on the water buffalo but there are 150 million of them in the developing world--equivalent to about one-fourth of the number of cattle there. Now researchers are turning to the water bufflo and some interesting findings are being reported. On low-quality pasture the animal apparently can produce more meat than cattle. In a taste test in Australia water buffalo meat was chosen as being more delicious than the meat of Angus and Hereford cattle, the main beef breeds.

Sudan appears to have large amounts of territory in Upper Nile Province (at least) where water buffalo should thrive. Sudanese animal scientists should study the available literatire (FAO recently published a large book* on the animal) and trial introductions from Egypt and perhaps from the Far East or Australia should be considered.

## CRAYFISH

Crayfish are omnivorous feeders. They reduce growths of aquatic vegetation when they occur in large number. Several genera that feed on plants include Procambarus, Cambarus, and Orconectes.

Procambarus clarkii, which has attained importance as a commercial food product in Europe and the United States, was introduced into the Sudan from Spain in October, 1975.

The crayfish are bottom feeders and will readily supplement the use of herbivorous fish in ponds and artificial impoundments. They provide an excellent source of protein. The crayfish digs burrows up to 0.5 meter deep in soft bottom soils which makes them difficult to harvest.

### Recommendations

1. Studies of the use of crayfish should be continued; however, they should also be restricted to artificial ponds for controlling aquatic weeds.

2. The palatability of numerous rooted submersed aquatic plants to the crayfish Procambarus should be determined.

## BIRDS

Chinese white geese will reduce stands of aquatic weeds in ponds. The elimination of weed growth is slow, often taking up to two years. In Malaysia the geese are combined with common carp to obtain more rapid and complete control.

Dabbing ducks eat aquatic vegetation and frequently will remove weed growths when populations of the ducks are large. The enrichment of the water by faeces of the ducks increases the turbidity, shading out submersed plants.

## OTHER VERTEBRATES

Other vertebrates that have been observed eating aquatic vegetation include the hippopotamus, turtle, baboon, antelope, and the rodent, hyrax. Water hyacinth was noticed to be lacking when large numbers of hippopotamuses

---

* "The Husbandry and Health of the Domestic Buffalo." W. Ross Cockrill, Editor. FAO, Rome, 1974.

inhabited an area. Increased surveillance of these animals should be made, and those that show potential should be exploited.

## REFERENCE

"The Husbandry and Health of the Domestic Buffalo." W. Ross Cockrill, Editor. FAO, Rome, 1974.

# CHAPTER IX

## CHEMICAL CONTROL

In the Sudan, use of 2,4-D at the rate of 4 lbs active ingredients per feddan (one feddan equals 1.038 acres) has proved satisfactory in the control of water hyacinth.

### METHODS

The following methods have been employed in the Sudan:

- Aerial spraying--by fixed-wing aircraft and helicopters in the larger infested areas,
- Spray launches--using high pressure spraying equipment in most infested areas; and
- Unimog (4-wheel drive) cars and knapsack sprayers--in infested areas along river banks.

### LIMITATIONS

Aerial application is limited to the short dry season in the southern infested regions. In other regions spraying 2,4-D is prohibited where crops susceptible to 2,4-D are grown. There is some loss of chemical during aerial application due to drift.

#### Unimog-cars, and Knapsack Sprayers

Spraying from launches suffer from lack of uniform cover of the sprayed chemical and improper calibration. There is a lack of trained personnel in application technique, and shortages of equipment and spare parts.

### RECOMMENDATIONS

1. The current control program should be continued and intensified.

2. There is a need for further investigation to produce better coverage and to reduce the amount of chemical lost into the atmosphere. This can be achieved by improving spraying techniques and spraying equipment.

3. The possibility of using low-volume application in remote areas, e.g., the Sudd, should be investigated in order to cover more infested areas with the same load.

4. The use of additives to reduce the drift should be tested.

5. The use of helicopters should be intensified to circumvent the problem relating to lack of landing strips for fixed-wing aircraft.

6. Improving, standardizing, checking, and increasing spray equipment for spray launches as required.

7. Training of personnel in application techniques should be expanded.

8. There is an urgent need for joint effort between the Ethiopian and Sudanese authorities, particularly in the field of aerial chemical control along the Akobo and Gila Rivers and other tributaries that originate in Ethiopia.

9. Alternative chemicals for water hyacinth control in areas where 2,4-D cannot be used should be investigated. The following chemicals that have shown promise in small-scale trials are suggested for testing in the Sudan:

| | |
|---|---|
| Diquat | Glyphosate |
| Diquat plus 2,4-D | Asulam |
| Paraquat | Ametzyne |
| Paraquat plus 2,4-D | Ametzyn plus 2,4-D |

## CHEMICAL CONTROL OF AQUATIC WEEDS IN CANALS

Mechanical and manual methods of control in the past provided satisfactory means for controlling most weed species. These methods of control were successful because of the availability of cheap labor. With labor becoming expensive and the canalization system in the country more extensive, the effectiveness of these methods leaves much to be desired.

A limited amount of experimental work was carried out in chemical weed control. The results obtained so far did not find their way to the canalization system of the agriculture production schemes for the following reasons:

- Canal water is still used by the local inhabitants for drinking and domestic purposes, which discouraged research on chemical weed control. (The limited information obtained was from a closed canal system specially prepared for the purpose.)

- No information is available on the side effects of herbicides used in irrigation canals.

Because of the urgent need for control of canal weeds in certain canals and despite the difficulties mentioned, it is recommended that the following chemicals be tested provided that the treated water not be used for domestic purposes:

- for submerged weeds
  - Acrolein
  - Xylene
  - Endothall
- for semi-aquatic weeds
  - Ametrole
  - Dalapone
  - Glyphosate
  - Ametzyne

## Limitations for Herbicides Already Used or Recommended for Further Testing of its Biological Activity Against Water Hyacinth

### 2,4-D-Amine

2,4-D-Amine may cause damage to a number of crops such as cotton and vegetables either in the form of spray drift, in the form of irrigation water, or from empty containers that have not been cleaned completely. Water is not potable immediately after its application. Insufficient information is available on its persistence or on its direct or indirect effects on fish, fish breeding, and fish feed under Sudanese conditions.

### Diquat and Paraquat

Diquat and Paraquat are inactivated rapidly in presence of clay minerals in water. This may reduce biological activity, when such water is used as carrier; they are persistent when absorbed by clay minerals.

### Glyphosate

Absorption by clay minerals in the water (as carrier) may reduce biological activity. Persistence in water is not known. There is no danger, however, when contaminated water is used for furrow irrigation. Contaminated water may damage emerged parts of crop plants when the type of irrigation cannot exclude contact with those parts.

Ametryne

Ametryne is relatively persistent. It is of low acute toxicity to mammals and fish. Contaminated water may damage crops (except sugarcane).

Asulox

Little is known about its behavior in aquatic systems. It is of low toxicity to mammals.

### Herbicides Recommended for Further Testing of their Biological Activities Against Weeds in Irrigation and Drainage Systems

Submerged Weeds

Acrolein. Since it is a general biocide, it is toxic to all living organisms and needs special application techniques. Contaminated water is not potable and not suitable for irrigation purposes.

Xylene is toxic to fish. Contaminated water is not potable.

Endothal. Water is not potable when heavily contaminated and not suitable for irrigation.

Semi-Aquatic Weeds

Amitrole is of low acute toxicity to mammals and fish but claimed to have carcinogenic effects.

Dalapon is of relatively low toxicity to mammals and fish.

Glyphosate and Ametryne. See previous discussion of these chemicals

## RECOMMENDATIONS

1. Since 2,4-D is used quite extensively, more knowledge about its behavior in environment and on its direct and indirect side effects on other living organisms is absolutely necessary. Residue studies and investigation of its effects on organisms are highly recommended.

2. As far as other herbicides are concerned, studies of their biological activity against the aquatic weeds under question have priority. Residue studies and investigation on possible side effects have to follow next, but before introduction of the herbicides for practical use.

3. There is an urgent need for precautionary or preventive measures against the introduction of problematic weed species into proposed or newly established agricultural schemes and man-made lakes.

# CHAPTER X

## WASTEWATER TREATMENT

All countries must cope with the problem of treating domestic, animal, and industrial wastewaters. One of the most promising approaches toward solving the problem and at the same time recovering nutrients and minerals is the use of floating vascular aquatic plants such as water hyacinth. The U.S. National Aeronautics and Space Administration (NASA) National Space Technology Laboratories (NSTL) has made significant progress in developing an integrated program utilizing a systems approach to the application of water hyacinth in removing a maximum amount of nutrients and toxic chemicals from domestic and industrial wastewaters. This systems approach involves the regular harvesting of water hyacinth grown in wastewater treatment lagoons to achieve maximum removal of nutrients and toxic chemicals (found in industrial wastes) followed by the utilization of these plants to produce useful products.

Many researchers have studied the nutrient-removal capability of water hyacinth (Wolverton and McDonald, 1975; Miner, 1971; Rogers and Davis, 1972). In growth-rate studies, water hyacinth were observed to produce 500 - 800 lbs of dry plant material per acre per day when grown in a nutrient-enriched media such as a domestic sewage lagoon.

Based on this growth rate and a surface area coverage of 100 tons per acre of wet plant material, one acre of water hyacinth is capable of removing the following amounts per day:

| Element | lbs removed/acre/day |
|---|---|
| carbon | 272 |
| nitrogen | 22 |
| phosphorus | 7.2 |
| potassium | 20 |
| calcium | 9.8 |
| magnesium | 2 |
| sodium | 16 |

Therefore, four acres of water hyacinth could remove all of the nutrients from the waste of 5,000 people when harvested at a rate of one-third the surface area every two weeks.

The advantages of a water hyacinth filtration system are:

- Flexibility in adjusting the surface area and wastewater retention time necessary to treat the effluent to meet the required legal standards.
- Removal of nutrients necessary to support pathogenic growth, thus helping to decrease the bacterial population.
- Removal of total phosphorus and adjustment of the pH to 6.5 - 7.5.
- Elimination of the need for future investment in expensive sewage treatment plants.

Other studies such as the one by Miner et. al., 1971, with swine waste have demonstrated the potential in treating animal waste and thus recovering lost nutrients and minerals.

One possible complication that should be explored is the potential infestation by mosquitoes in water hyacinth lagoons. This problem could possibly be solved by using fish to eat the mosquito larvae.

Water hyacinth is also a very good biological agent for removing the pollutants from industrial wastewaters. These industrial wastewaters would also be retained in controlled systems much like domestic sewage lagoons. One limitation to the use of water hyacinth in chemical waste treatement is the salt content of the wastewater. Waterhyacinth can only tolerate salinity levels up to approximately 1.6 parts per thousand.

Water hyacinth grown in domestic or animal wastewater could be a valuable source of fertilizer, animal feed, and methane gas production. However, plants grown in industrial wastewater are known to be safe only for methane gas production by anaerobic (without oxygen) fermentation. All water hyacinth obtained from these systems should be screened for chemical residues, pesticides, and toxic heavy metals prior to use as food, feed products, or fertilizer.

Drinking water purification utilizing water hyacinth is presently being investigated by NASA's National Space Technology Laboratories. This effort is directed toward removing carcinogenic agents from drinking water.

## RECOMMENDATIONS

1. Developing countries such as the Sudan should look at the long-range application and economics of water hyacinth as biological agents for treating domestic animal and chemical waste as development in these areas proceeds.

2. Use of water hyacinth may be applicable now or in the near future for wastewater treatment in Egypt.

REFERENCES

1. J. R. Miner, J. W. Wooten, and J. D. Dodd. Water hyacinth to further treat anaerobic lagoon effluent. Amer. Soc. Agri. Eng. Proc. 271, 170-173 (1971).

2. H. H. Rogers and D. F. David. Nutrient removal by water hyacinth. Weed Sci. 20, 423-428 (1972).

3. B. C. Wolverton and R. C. McDonald. Water hyacinth and alligator weeds for removal of lead and mercury from polluted waters. NASA Technical Memorandum TM-X-72723 (1975).

4. B. C. Wolverton and R. C. McDonald. Water hyacinth for upgrading sewage lagoons to meet advanced wastewater treatment standards. NASA Technical Memorandum TM-X-72729 (1975).

# CHAPTER XI

# MULCH, COMPOST, AND POTTING MATERIAL

Sudanese scientists already have experience with conversion of water hyacinth to soil additives. The following are details of the experimental findings.

## MULCHING MATERIAL

An area thoroughly infested with sedge weed (*Cyperus rotundus*) was chosen at the Faculty of Agriculture, Shambat. Four quantities of 9, 20, 40, and 60 kgs of the water hyacinth material per plot (3 x 3.7 m.) were applied and replicated thrice in random block design.

### Weed Control

The visible effect of the mulch on sedge was remarkable; the intensity of smothering (burning) was notable and it increased with increase in the mulch material per unit area.

Twenty uniform sound sedge tubers were dug from each plot. The time required to 50 percent sprouting increased with increase of the mulch quantity and the mean growth rate was very much reduced with increase in mulch material.

TABLE 1 Number of days for 50 percent sprouting and the mean growth of leaves of sedge subsequent to mulch treatments.

| Treatment | Mean Days to 50 Percent Sprouting | Mean Growth Rate (mm/day) |
|---|---|---|
| Control (no mulch) | 5.56 | 5.20 |
| 20 kg per plot | 6.52 | 5.00 |
| 40 kg per plot | 8.00 | 3.10 |
| 60 kg per plot | 9.25 | 3.00 |

## Soil Moisture Reservation

Table 2 shows that the amount of water kept by the soil was positively correlated with the weight of mulch material applied per plot. The moisture content at the soil surface (0 - 1/2 in.) was increased by about 33 percent when applying 60 kg of the mulch material. At 12 in. depth, however, the variation between the control and the 60 kg. was small.

TABLE 2 Effect of the mulch on soil moisture reservation at different soil depths.

| Treatment | Soil Depth (inches) Surface (0 - 1/2) | 6 | 12 |
|---|---|---|---|
| Control (no mulch) | 14.78 | 15.01 | 21.11 |
| 20 kg per plot | 17.25 | 20.87 | 22.25 |
| 40 kg per plot | 22.35 | 22.36 | 23.89 |
| 60 kg per plot | 22.07 | 25.94 | 26.24 |

## COMPOST AND POTTING MATERIAL

Many recommendations were made for the use of water hyacinth as compost because when added to soil it releases nutrients to crops. This enhances plant growth and improves the physical soil conditions. It has been reported that potash is the chief constituent. If rotted, the residue contains about the same amounts, or more, of nitrogen and phosphoric acid as ordinary farm yard manure and it is several times as rich in potash. In the United States it has been used as potting material in which ornamental plants are grown successfully.

Another use of water hyacinth is the extraction of salt from its ashes, which are mostly potash and potasium chloride.

The nutrient content of water hyacinth varies with the location, season, and water quality.

## CHAPTER XII

## COMPETITIVE PLANTS

The competitive displacement of aquatic and semi-aquatic plants has been observed. It is a normal ecological process, the succession of plants. The replacement plant is sometimes less desirable than the one it replaces; however, the plant succession can be manipulated to encourage succession of a more desirable species. Several aquatic plants occurring in the biocenose will do this.

Two short-growing perennial spikerushes, dwarf spikefush [Eleocharis coloradoensis (Britt.) Gilly] and slender spikerus (Eleocharis acicularis) have been used to displace rooted, submersed, aquatic plants such as the pondweeds (Potamogetons) in California. These plants reproduce by seed and tubers, thereby allowing the plants to withstand temporary periods of drought.

Several grasses have been used to displace cattail and ditchbank weeds. Paragrass (Brachiaria mutica Forsk Stapf.) has been used in India to displace cattail (Typha angustata Bory and Chaub) that had previously been cut to remove the foliage. Kikuyu grass (Pennisetum sp.) has been planted along the banks of new ponds in Uganda, which prevented the establishment of weeds at and near the waterline. Paspalum disticum has been used along canal banks in Egypt and successfully displaced bank weeds and prevented their reestablishment. A companion grass Echinochloa stagninum has been observed to form smothering mats. The plant also has the peculiarity of forecasting the presence of water hyacinth.

Once established, the competitor plants are capable of providing long-term control of weeds with minimum maintenance costs.

Spikerushes are difficult to establish in flowing water, waters subjected to violent wind action, and gravelly, coarse, and hard-packed soils. The propagules of spikerushes are difficult to obtain. The spikerush nursery recently established at Davis, California, should have a supply of seed in 2 or 3 years. A number of tubers for preliminary studies are available now. The grasses are indigenous to Africa and supplies of propagules or grown plants may be readily available.

## RECOMMENDATIONS

1. The dwarf and slender spikerushes should be brought into one or more countries of the Nile Basin and the plants grown in quarantine facilities to prevent their escape before sufficient data have been evaluated to determine their safety.

2. The grasses, depending on their suitability and adaptability, should also be imported, or if native to the area should be tested to determine their feasibility for displacing and preventing the encroachment of undesirable plants.

## APPENDIX A

## WORKSHOP PARTICIPANTS

### SUDAN

DR. MOHAMMED OBEID - Department of Botany, Faculty of Science, University of Khartoum

SAYED HASSAN ABBAS - Director Plant Protection Administration, Khartoum North

DR. MIRGHANI TAG EL SEED - Hydrobiological Research Unit, Faculty of Science, University of Khartoum

DR. KAMIL BESHIR EL TIGANI - Head Water Hyacinth Control Section, Plant Protection Administration, Khartoum North

PROF. HUSSEIN EL SAYED OSMAN - Department of Animal Production, Faculty of Agriculture, University of Khartoum

DR. ASIM L. EL MAGRABY - Hydrobiological Research Unit, Faculty of Science, University of Khartoum

DR. ALI MOHAYAD BANNAGA - Director Agricultural Research Council, National Council for Research

SAYED SOGHARYOON EL ZEIN - Chairman, The Board of Directors, The Public Corporation of Irrigation Works and Earth Moving, Khartoum North

DR. MOHD. EL MAHDI BESHIR - Agricultural Research Corporation, Wad Medani

DR. A/RAHMAN EL TAYIB A/HAFEEZ - Department of Horticulture, Faculty of Agriculture, University of Khartoum

G.A. EL HAG - Faculty of Agriculture, University of Khartoum

DR. A/MONEIM KARAR - Head, Locust Control Section, Plant Protection Administration

SAYED KAMAL MAHGOUB - Inspector, Water Hyacinth Control Section, Plant Protection Administration, Malakal

SAYED EL FADIL EL RASHID - Senior Inspector, Water Hyacinth Control Section, J. Aulia

DR. A/AZIZ SAAD - Entomologist, Plant Protection Administration

AKASHA MOHAMED ALI - Water Hyacinth Control Section, Plant Protection Administration, Khartoum North

MR. T.T. GEORGE - Agriculturist, Fisheries and Hydrobiological Research Section

MR. SAMIR YANNI MISHRIGI - Acting Head, Fisheries and Hydrobiological Research Section

DR. ABDALLA M. HAMDOUN - Weed Specialist, Agricultural Research Corporation, Wad Medani

DR. IMAM EL KHIDIR - Acting Head, Department of Crop Protection, Faculty of Agriculture, University of Khartoum

DR. MAGZOUB OMAR BESHIR - Crop Protection Department, Faculty of Agriculture, University of Khartoum

## SUDANESE-GERMAN WATER HYACINTH CONTROL PROJECT

PROFESSOR W. KOCH - Abteilung fur Herbologie, 7000, Stuttgart 70, Postfach 106, Guterstation: Stuttgart-Mohringen, West Germany

MR. VOLKHART LEFFLER - Sudanese-German Water Hyacinth Control Project, P.O. Box 6068, People's Hall, Khartoum

MR. K. MARTIN LUTH - Sudanese-German Water Hyacinth Control Project, P.O. Box 6068, People's Hall, Khartoum

DR. F. BISCHOF - Abteilung fur Herbologie, 7000, Stuttgart 70, Postfach 106, Guterstation: Stuttgart-Mohringen, West Germany

## EGYPT

PROF. MOUSTAFA IMAM MAHMOUD - Head, Department of Natural Resources, Institute of African Studies, Cairo University

DR. MAHMOUD A'GAWI ZAHRAN - Department of Botany, Faculty of Science, Mansoura University, Mansoura

DR. MOHAMMED KAMAL ZAHRAN - Ministry of Agriculture, Cairo

DR. HAMDI A 'ZIZ MOURSY - National Research Centre, Dokki, Cairo

ENGINEER JEAN KAMIL ABDEL SEED - Institute for Channel Maintenance and Weed Control Research, Ministry of Irrigation, 22 SH. El Gala, Cairo

## ETHIOPIA

W/O GUERRA GEBREMASCAL - Head of National Water Resources Commission, Laboratory Division, Addis Ababa

ATO ADEFRIS BELLEW - Regional Director, Desert Locust Control Organization, Addis Ababa

## INDONESIA

DR. MOHAMMED SOERJANI - Director, Program for Tropical Biology, BIOTROP, Bogor

## MOZAMBIQUE

NANCY COE - Lake Cabora Bassa Weed Control Project

## UNITED STATES OF AMERICA

LARRY O. BAGNALL - Associate Professor, Department of Agricultural Engineering, University of Florida, Gainesville, Florida 32611

JAMES F. HENTGES - Professor, Department of Animal Science, University of Florida, Gainesville, Florida 32611 (Chairman of the American Participants)

B. DAVID PERKINS - Research Entomologist, Agricultural Research Center, U.S. Department of Agriculture, Fort Lauderdale, Florida 33314

BILL C. WOLVERTON - Director, Environmental System Development Team, National Space Technology Laboratories, National Aeronautics & Space Administration, Bay Street, Bay St. Louis, Mississippi 39520

RICHARD R. YEO - Research Botanist, U.S. Department of Agriculture, Department of Botany, University of California, Davis, California 95616

M.G.C. MCDONALD DOW - Deputy Director, Board on Science and Technology for International Development, National Academy of Sciences, Washington, D.C. 20418 (Staff)

NOEL D. VIETMEYER - Professional Associate, Board on Science and Technology for International Development, National Academy of Sciences, Washington, D.C. 20418 (Staff Study Director)

REBECCA MCDONALD - Environmental System Development Team, National Space Technology Laboratories, National Aeronautics and Space Administration, Bay St. Louis, Mississippi 39520 (Observer)

## WORKING SECTIONS

### Biological Control

Moustafa Imam (Chairman)
Richard Yeo (Rapporteur)

Ali M. Bannaga
T.T. George
A.I. el Moghraby
Kamal Mahagoub
Samir Yanni Mishrigi
El Imam El Khidir
Abdel Moneim Hassan Karrar
Magzoub Omer Bashir
Nancy Coe
Friedrich Bischof
David Perkins
Jean Kamel

### Chemical Control

Abdalla Hamdoun (Chairman)
W. Koch (Rapporteur)
Kamil Beshir El Tigani (Rapporteur)

Guerra G. Maschal
Hassan Abbas
M. Luth
Mohamad Soerjani
Mirghani Tag El Seed
El Fadil El Rashid
Richard R. Yeo
Akashi Mohamed Ali

### Utilization

Hussein el Sayed Osman (Chairman)
Larry O. Bagnall (Rapporteur)
A.T. Abdel Hafeez (Rapporteur)

Rebecca C. McDonald
Bill Wolverton
Volkhart Leffler
Hamdy A. Moursy
Akasha Mohamed Ali
James F. Hentges, Jr.

## APPENDIX B

## WORKING SECTION AGENDA

| Time | | Biological | Chemical | Utilization |
|---|---|---|---|---|
| | | Chairman: Dr. Mustafa<br>Rapporteur: Dr. Yeo | Chairman: Dr. Hamdoun<br>Rapporteurs: Dr. Beshir<br>Dr. Koch | Chairman: Dr. Osman<br>Rapporteurs: Dr. Bagnall<br>Dr. Hafeez |
| Nov. 27<br>Thursday | 0900 - 1100 | Fish | Water hyacinth in Nile River | Wastewater nutrient removal<br>Utilization for biogas (methane) |
| | 1100 - 1315 | Insects | Water hyacinth in calm waters, marshes, etc. | Harvesting, dewatering, processing. |
| | 1700 - 1800 | Competitive plants | Canal weeds, submerged weeds | Utilization for:<br>Compost, potting, media mulch, fertilizer<br>Silage<br>Dry feed<br>Construction materials |
| Nov. 28<br>Friday | 0900 - 1030 | Pathogens, vertebrates such as manatee and ducks | Semi-aquatic weeds | |
| | 1100 - 1145 | Plenary report | | |
| | 1145 - 1230 | | Plenary report | |
| | 1230 - 1315 | | | Plenary report |

## APPENDIX C

## THE WATER HYACINTH

One of the most successful colonizers in the plant world, the water hyacinth has spread within a hundred years from its home base in South America to at least fifty countries around the globe. The hyacinth exploits its freshwater habitat to the fullest, uses solar energy efficiently, and is enormously productive. It propagates by several mechanisms and apapts to changing climate and water quality. Amazingly robust, the hyacinth can even convert from an aquatic plant to a terrestrial one if its waterway dries up.

The water hyacinth is a beautiful organism, and this has largely been the cause of its dispersion. People spread the plant, captivated by its flowers and floating rosette of green leaves.

It has spongy, swollen petioles, or leafstalks, that allow it to float. The petioles free the water hyacinth from a terrestrial grip and give it the ability to move. The rosette of petioles creates a circle of floats that prevents the plant from capsizing. When the plants are crowded together, however, the petioles grow tall and slender. In this way an acre can be packed with 180 tons of hyacinth. Water hyacinth roots hang in the water. The airy white or lavender flowers, borne on a spike, rise from the center of the plant. Their purple-veined petals have yellow, diamondlike centers on their upper lobes.

The water hyacinth reproduces mainly in a vegatative, or nonsexual, manner by means of a slender horizontal runner, called a stolon, that it sends out across the surface of the water. As the stolon grows, a new plant forms at its tip, and in a matter of days a parent is surrounded by offspring. As their leaves and roots develop, the offspring begin sending out their own stolons to form a third generation. In one experiment two parent plants were surrounded by 300 offspring in 23 days and by 1,200 after four months. In the wild, water hyacinth plants can double their number within 10 days. Under favorable conditions, 10 plants can multiply to 600,000 and overspread an acre of water in only eight months

Small wonder the water hyacinth is hated and disowned in many countries. Its colloquial names attest to the bitterness with which it is regarded. It is called the blue devil (in Bengal), the Bengal terror (elsewhere in India), and the Florida devil (in South Africa, where the plant is commonly supposed to have come from the Sunshine State). In Bangladesh it is known as the German weed because it became prevalant during World War I, and even today some think that its introduction to the subcontinent was a military inspiration. In Sri Lanka (formerly Ceylon), the hyacinth is called Japanese trouble in the belief that the British planted it during World War II to induce the expected Japanese invasion forces to land their aircraft on its flat green surfaces and thus come to a soggy end.

The water hyacinth is a sturdy plant. Its core is a fleshy vertical stem, called a rhizome, from which the roots, leaves, flowers, and stolons develop. The rhizome floats an inch beneath the water surface where it is protected by the water and by juvenile leaves folded tightly around it. Prolific productivity is another characteristic of the water hyacinth. It manufactures solid vegetable matter more efficiently than most other plants. Indeed, some botanists have speculated that the water hyacinth may be the most productive plant on earth. The water hyacinth's growth can literally be seen; a noticeable elongation of the leaves and stolons is visible from hour to hour. This comes about because with each part of solid laid down, the plant incorporates up to 19 parts of water. The huge volumes of vegetation created in this manner are about 95 percent liquid. This ratio of water to vegetable matter largely accounts for the enormous expansion of hyacinth greenery across a waterway.

The hyacinth's growth is exerted sideways, not vertically as in most plants. Its aquatic environment provides it with lateral space. Arranged in a single rosette, its leaves seldom shaded, are usually well shaped and spaced for capturing sunlight. Because of these factors, green rafts of hyacinth expand rapidly and inexorably over the water. Then winds, waves, and currents stretch and fracture the interlinking stolons; when these rot away, the rafts split apart, freeing sections that can be several acres in area. The freed colonies thrust relentlessly across a lake or down a river, ever growing, ever splitting into still more colonies. In enclosed waters the rafts merge into a continuous shore-to-shore mat. With further reproduction, the mat thickens and tightens until it is difficult to perceive the water beneath it.

Unfortunately, man has only imperfect weapons with which to battle this superplant. Despite every effort, the water hyacinth persists to this day in all the regions it has ever invaded. It has never been eradicated anywhere. Although the water hyacinth can be a pest, it has good qualities as well. High yield and rapid growth are generally deemed desirable. The hyacinth, which grows on water, rather than on overtaxed land, does not require irrigation, fertilizer, or seeds. Grown and harvested under supervision, it will absorb pollutants from our befouled waterways. Perhaps one day we will harness this prolific plant and thereby transform today's superpest into tomorrow's supercrop.