Increasing The Efficiency of Aquatic Plant Management Through Processing[1]

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ABSTRACT

While mechanical harvesting is generally considered an ecologically sound approach to the control of excessive aquatic plant growth, its application has been limited by high unit costs. The efficiency of mechanical harvesting can be greatly increased by (1) reducing the weight, (2) reducing the volume, and (3) improving the handling characteristics of the harvested plant material by means of processing. Possibilities for utilization and disposal of harvested aquatic plants are also discussed.

INTRODUCTION

Excessive growth of aquatic plants in lakes and waterways reduces the beauty, utility, and recreational potential of these bodies of water. This phenomenon, which is of increasingly widespread concern (8) is frequently attributable in major part to human activities which raise the nutrient level of the water. These plants, however, also serve important positive ecological functions. These include addition of oxygen to the water during photosynthesis, provision of habitat for various aquatic life, stabilization of bottom muck, synthesis of food for aquatic animals from sunlight and minerals, and possible inhibition of free-floating algae (7). Eradication, even if feasible, would therefore be a questionable goal.

Maintenance of nutrient levels below those which produce abundant plant growth would represent a basic solution. In most cases, however, this does not appear to be an attainable goal for the foreseeable future. Consequently, many knowledgeable aquatic ecologists feel that one of the better presently available techniques for improving water conditions is the cutting and removal of aquatic vegetation. This method gives immediate relief from the nuisance conditions and restores much of the original usefulness and beauty of the water resource without drastically upsetting the ecosystem. Mechanical management, moreover, adds no foreign substances to the water. It also gives the option of utilizing the harvested plant material for nutritional or other purposes when and where this is economically sound. While the quantity of nutrients removed from the water by harvesting of aquatic plants generally appears to be modest relative to the supply, it is at least a step in the right direction, and will become relatively more significant as nutrient inflow is decreased through improved watershed management.

Research by plant ecologists on small hand-harvested plots has shown that one or two cuttings per year, depending on the depth and water clarity, appear to be sufficient to eliminate most nuisance situations in lakes of the north central region of the nation (5). Cutting is usually accomplished by a barge equipped with an underwater cutter bar immediately in front of a porous conveyor which brings the cut material onto the deck. The plant material is transported to shore either by the harvesting barge or by another barge which shuttles between the harvesting site and shore. Plant material is frequently disposed of in land fill sites some distance from the lake. Aquatic plant management by means of mechanical harvesting has been handicapped by its low productivity and consequent high cost in comparison with analogous agricultural operations.

Low productivity is caused largely by (1) the low forward speed attainable by the harvester when pushing the large conveyor through the water, and (2) the weight and bulk of materials to be handled and transported. Plant material removed from the lake generally contains more than 90% moisture. In other words, for every pound of dry matter harvested, approximately 9 pounds of water must also be handled. Any method which substantially reduces the moisture content of the plants during the initial stages of harvesting can greatly increase the efficiency of the operation. A study was therefore initiated which seeks to determine the degree to which the weight and volume of aquatic plants can be reduced by processing.

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PHYSICAL PROPERTIES OF SUBMERGED AQUATIC PLANTS

Because of their natural habitat and condition of growth, aquatic plants have many anatomical and morphological adaptations which make them differ considerably from terrestrial plants.

An enlarged cross-section of a stem of Eurasian watermilfoil (*Myriophyllum spicatum* L.) is shown in Figure 1. The centrally located fibers, and the air canals give the plant physical properties that are quite different from those of the land plants which lack air canals and which have radially located fibers. Since the plant is lighter than the surrounding water (approximate specific gravity: 0.8) it is relieved of the task of supporting its own weight, and therefore, has no need to develop a strong main axis.

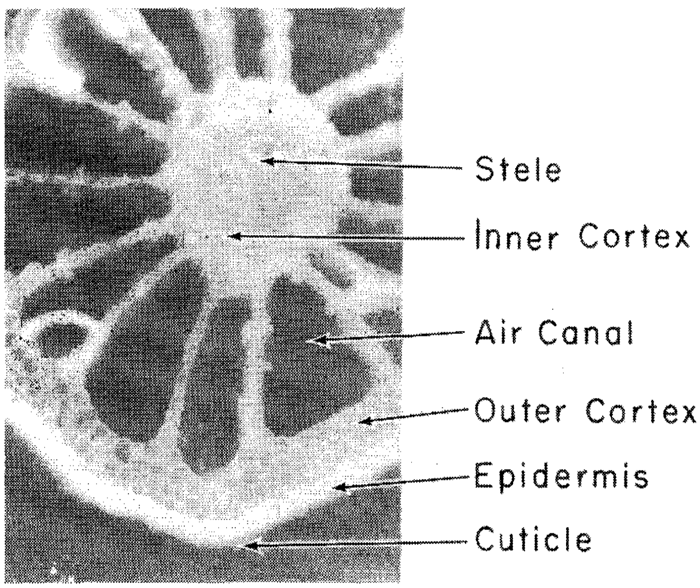

Figure 1. Cross Section through a stem of Eurasian watermilfoil

The air canals form a large gas filled intercellular system which dominates the entire anatomy. These air canals, which also accumulate the oxygen of photosynthesis, extend through the entire plant and conduct gas for respiration, particularly to the roots, which extend into the oxygen free ooze (12). The air canals are also responsible for the buoyancy of the weak stems.

Figure 2 shows the constituents, by weight and by volume of a mass of Eurasian watermilfoil as might be obtained by current harvesting operations. The low percentage of solids indicates a great potential for decreasing both the weight and volume of the mass by the expression of water and air.

PROCESSING STUDIES

Removal of Entrained Surface Moisture

Experiments were conducted to evaluate the suitability of a set of rubber-covered rollers, similar to oversized wringer rollers, for the removal of entrained surface moisture (Figure 3). The rollers used are 8.5 inches outside diameter by 16 inches long with a thickness of rubber of approximately 0.7 inch vulcanized onto a steel cylinder. These rollers are mounted in a press which can supply rotary motion as well as a force in the axial plane to force the rollers together.

Results of the tests are summarized in Table 1. Final moisture of the pressed residue averaged 78.4% and this probably represents mainly cellular moisture which is not readily removed by the rolls. Overall, it appears that a combination of low force, high speed, and low hardness will give the most satisfactory results from the standpoint

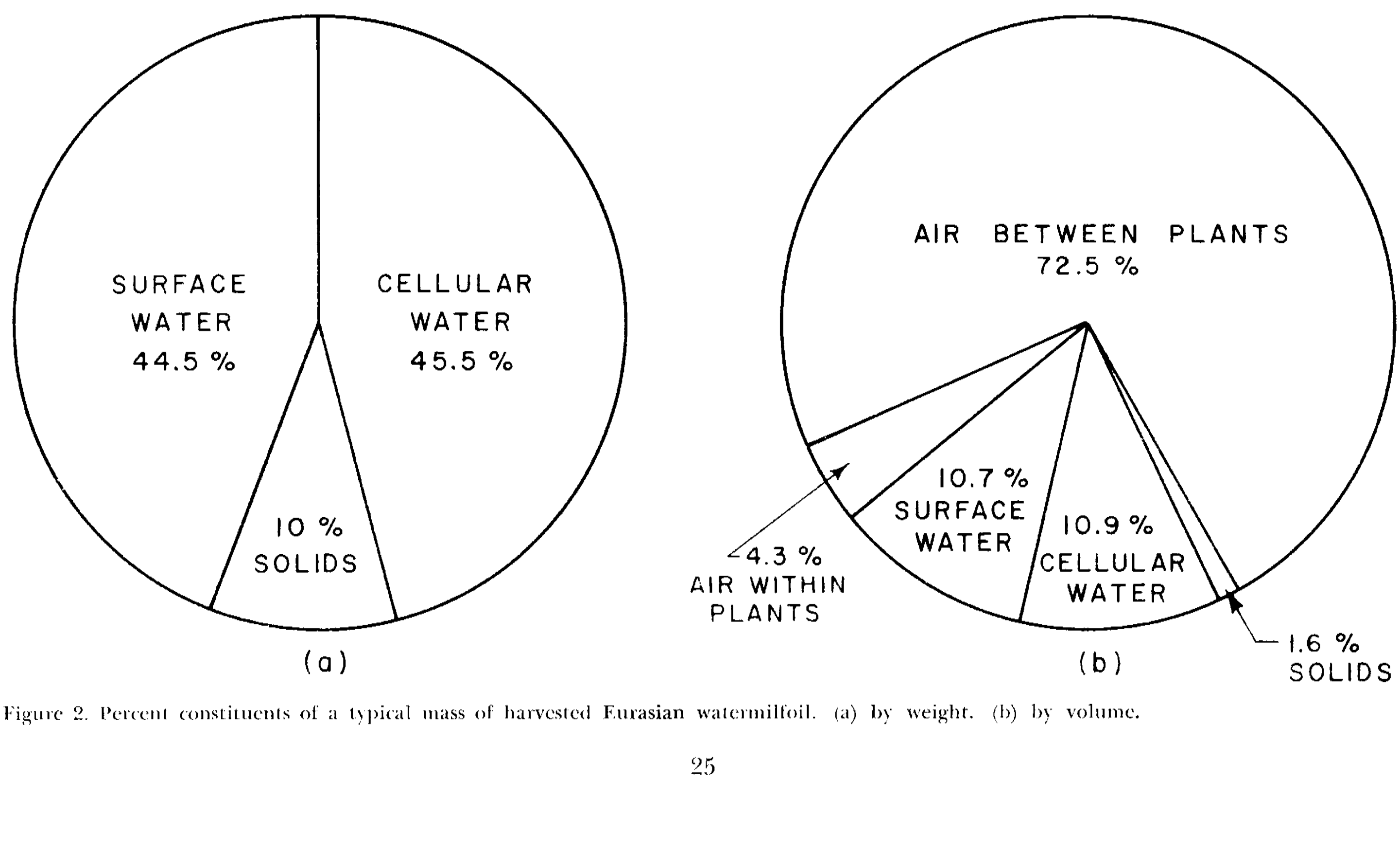

Figure 2. Percent constituents of a typical mass of harvested Eurasian watermilfoil. (a) by weight. (b) by volume.

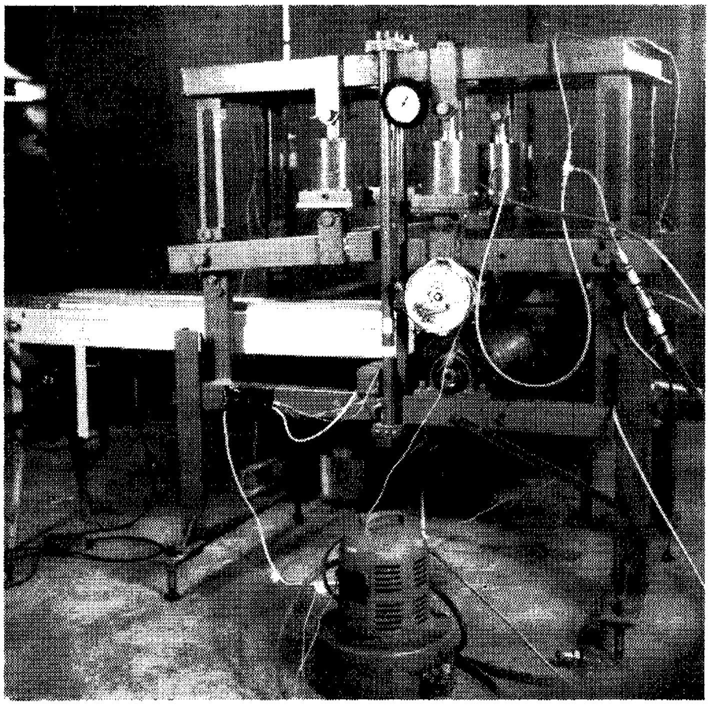

Figure 3. Roller press for removal of entrained moisture.

of surface moisture removal, throughout, and power requirement.

The rubber-covered roller press does an acceptable job of removing the entrained surface moisture. The throughput is reasonable and the power requirement is low. The press does not cause excessive cellular destruction, and hence results in an expressed liquid low in solids content and oxygen demand. This may be important if the expressed liquid is to be returned directly to the waterway. The rollers are capable of removing more than 50% of the water in the as-harvested vegetation and 48% of the initial weight of the plant material, as received from the harvester. They also reduce the volume of the plants to approximately 40% of the original value. However, the final moisture of the pressed residue is still quite high and further processing may be desirable for subsequent handling and disposal or utilization. Additional details on surface moisture removal are described by Koegel, *et al.* (9).

Use of Forage Choppers

After harvesting, aquatic vegetation is a bulky, tangled mass which is difficult to unload, or to convey with a well controlled uniform flow. Handling characteristics can be greatly improved by passing the harvested vegetation through a conventional forage chopper. After chopping, it can be handled by standard conveyors or augers and will flow uniformly. Chopping also drastically reduces the volume of the vegetation, allowing more to be stored or hauled in a given space. If a recutter screen (a screen through which the chopped material must be forced by the chopper knives) is used with the chopper, the effects of chopping are increased. An additional effect of chopping is improved dewatering. For a given pressing operation, more liquid can be expressed from the chopped vegetation than from non-chopped vegetation because of the cell rupture which takes place during the chopping operation.

The dewatering characteristics of vegetation subjected to various pretreatments were compared by means of a "standard" dewatering test. The test consists of placing a measured sample of the material into a cylinder press, one end of which is fitted with a fine screen, and applying 100 psi pressure to the sample for 1.0 hr. Moisture of the samples is determined at the end of this time.

Results of chopping, with and without recutter screens, and of the standard dewatering test, are shown in Table 2.

Removal of Cellular Moisture

The mechanical removal of cellular moisture may be accomplished as two sub-processes: (1) the rupture of a significant proportion of the plant cells, and (2) the ex-

TABLE 1. RESULTS OF RUBBER-COVERED ROLLER TEST.

Roller variable			As-harvested vegetation		Pressed vegetation[a]		Expressed liquid[a]		
Force (lb/ft roller)	Speed (RPM)	Rubber hardness (Rex No.)	Throughput tons/hr/ft of roller length	Specific Power H.P.-hr/ton	Percent moisture	Percent initial moisture removed	Percent solids	Percent of total initial solids contained	Chemical oxygen demand (ppm)
100	2	60	0.080	0.22	78.6	56.0	0.54	2.6	2,185
200	2	60	0.076	0.32	78.1	58.4	0.49	2.5	2,638
100	7	60	0.280	0.19	79.0	54.6	0.62	2.8	2,398
200	7	60	0.320	0.30	78.4	57.2	0.70	3.4	3,295
100	2	80	0.046	0.24	79.0	48.6	0.42	1.5	2,692
200	2	80	0.049	0.42	77.6	50.6	0.44	1.5	3,262
100	7	80	0.210	0.22	78.8	50.3	0.42	1.6	3,232
200	7	80	0.200	0.38	78.0	52.0	0.67	2.6	4,810

[a]Values are the mean of two replications

TABLE 2. EFFECTS OF CHOPPING EURASIAN WATERMILFOIL AND USE OF RECUTTER SCREENS (THEORETICAL LENGTH OF CUT: ¾ INCH).

Response	Control (as harvested)	Chopped without screen	Chopped; screen with 2 inch square openings	Chopped; screen with ¾ inch square openings
Bulk density (lb/ft³)	13.6	32.5	43.4	46.9
Percent original volume	100.0	41.8	31.3	29.0
Chopped throughout (tons/hr)	.....	28.0	25.3	16.5
Power requirement (hp)	....	8.93	8.55	10.9
Specific power requirements (hp - hr/ton)	.....	0.309	0.338	0.66
Final moisture (%) after standard dewatering test (1 hr @ 100 psi)	75.7	68.4	68.4	67.1
Percent of initial moisture removed by standard dewatering test (1 hr @ 100 psi)	42.4	59.4	59.0	61.8

pression of the liquid from the ruptured cells by some form of press.

Both the rupturing of cells (maceration) and the expression of liquid through and out of the porous plant matrix (fractionation) can be accomplished by applying a pressure gradient across the plant material. Maceration is essentially an instantaneous process which requires a certain minimum pressure gradient to rupture a significant proportion of cells. Fractionation, on the other hand, is a time dependent process, the amount of liquid expressed from macerated plant material depending on both the time and the pressure gradient (10). For example, a given amount of liquid may be expressed either at a low pressure gradient held for a long period of time or by some higher pressure gradient held for a shorter time period. While both maceration and fractionation are frequently carried out concurrently in the same piece of equipment, the dissimilarity of their requirements indicates that separation of the two processes may lead to greater efficiency.

Screw presses have been widely used for expressing liquid from a variety of materials. Such presses typically consist of an auger or screw rotating inside of a closely fitted, perforated, cylindrical housing (Figure 4). The material to be dewatered is carried from the inlet end to the outlet end of the press by the rotation of the screw (Figure 5). Compression takes place in the material by means of one or a combination of the following features: (1) gradually decreasing the pitch of the screw from inlet to outlet end, (2) using a tapered screw, and (3) using a variable restriction at the press outlet. The plant material to be dewatered may be macerated before using the screw press or it may be macerated by the mechanical action of the press itself, including the shearing of the material by stationary bars projecting from the inside of the press housing and the abrading of the material as it is forced longitudinally along the perforated casing. Some of the work to date using screw presses for the removal of cellular moisture from aquatic plants has been reported in detail by Bruhn *et al.* (3). The major results of these tests were that a well designed screw press could reduce the moisture of the plant material to 60 to 65%, and the weight and volume could be reduced to one-third and one-sixth of the original values, respectively, while losing less than 20% of the nutrients of the plant material in the expressed liquid (Figures 6 and 7). Thus, more than 80% of the nutrients are retained in the press residue.

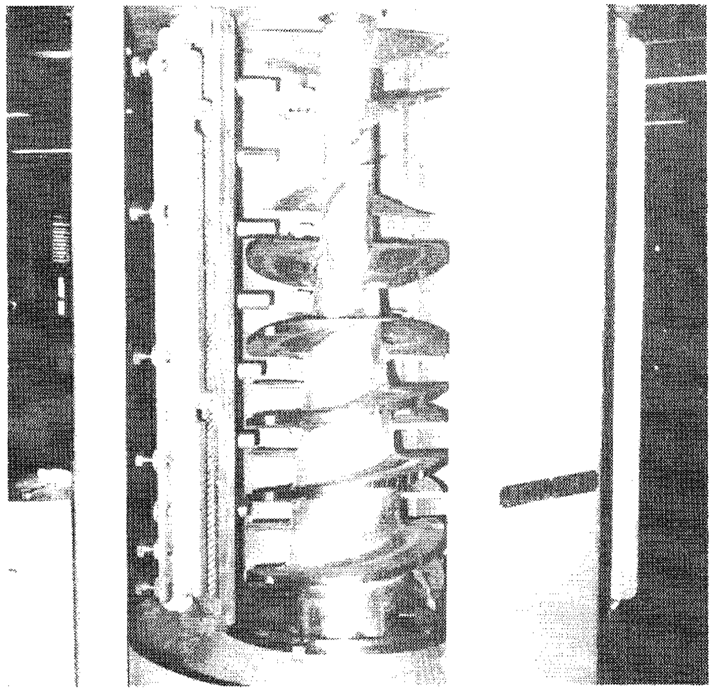

Figure 4. Interior of screw press.

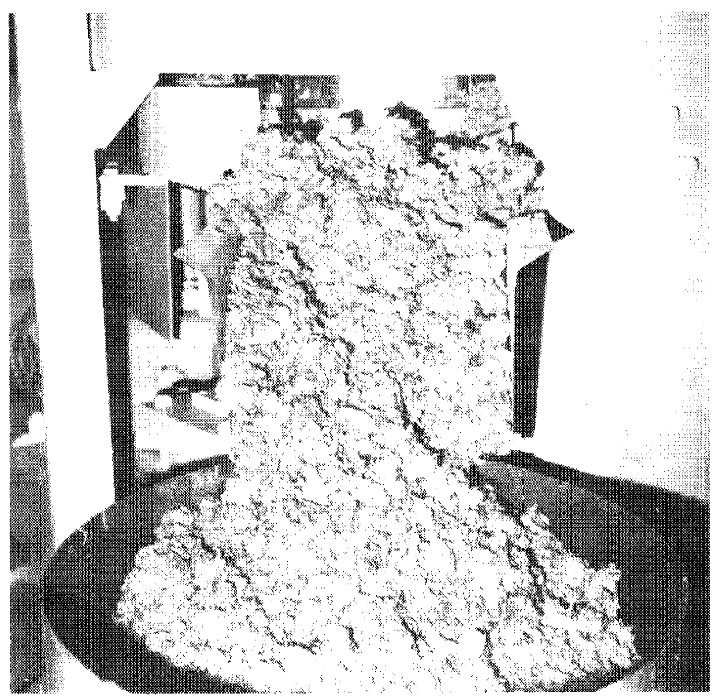

Figure 5. Dewatered vegetation discharging from screw press.

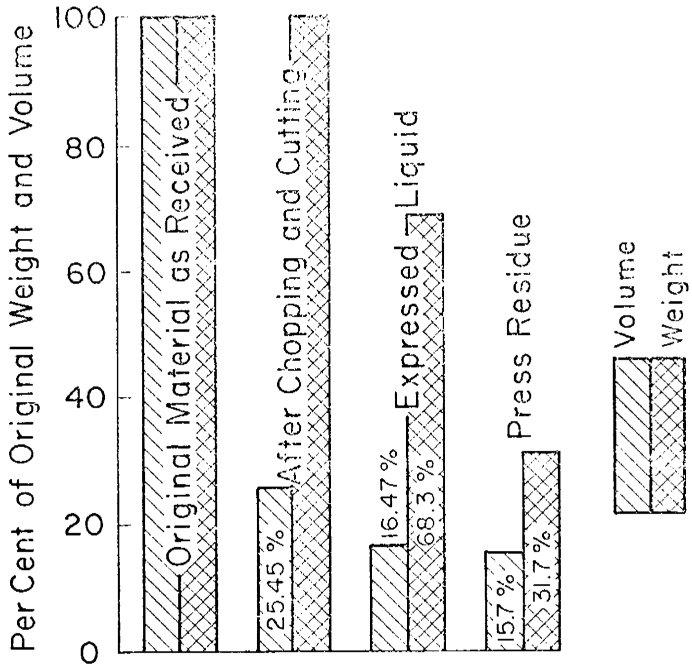

Figure 6. Volume and weight fractions resulting from chopping, recutting, and pressing.

Recent Work on Screw Press

Current work on a small, instrumented laboratory screw press indicates that such a well-designed press can reduce plant moisture to around 60% without expressing large amounts of solids with the juice. The small press also allows for easy control of the condition of the material being fed to the press, facilitating studies of the effects of pretreatments on dewatering and nutrient distribution.

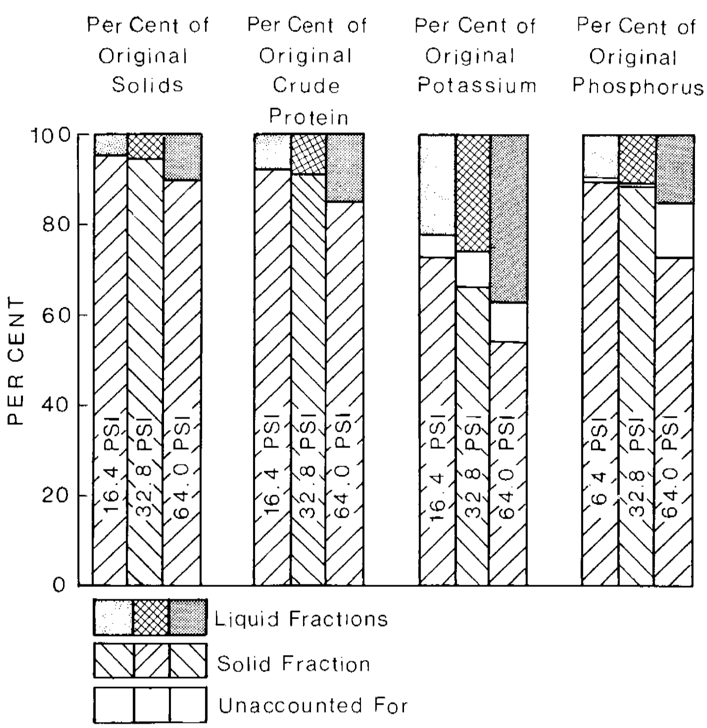

Figure 7. Distribution of original components to residue and liquid for varying material discharge pressure.

One reason for the use of the screw press in this work is its relative availability as a standard dewatering device. A number of other less-known press configurations exist, however, which could also be studied to determine their suitability for the removal of cellular moisture from aquatic vegetation.

In general, as more of the plant moisture is removed in a given press as a result of either increased pressures or more extensive pre-processing (e.g. chopping), the solids content and the oxygen demand of the expressed liquid is also increased. Therefore if the expressed liquid is to be returned to the lake, its oxygen demand may serve as a guide to the extent of dewatering which can be carried out without exceeding an allowable level. What constitutes a maximum allowable level depends on a number of factors and requires further study.

Heat treatment (blanching) of forage material was found to facilitate subsequent mechanical dewatering (4). Aboaba (1) found that blanching aquatic plants resulted in increased water extraction during subsequent pressing. More significantly he found also that blanching reduced the amount of solids in the expressed liquid.

Heat treatment of plant material causes protein denaturation or coagulation. The protein molecules then lose their waterbinding ability. This, coupled with the inability of the cell walls to maintain osmotic pressure, or possibly even some rupturing of the cell walls, facilitates the passage of liquid. Furthermore, coagulation causes entrapment of the cellular matter and hence results in smaller amounts of cellular matter lost with the liquid.

Table 3 gives the results of some preliminary tests. Blanching temperature was approximately 212 F in all cases. The "standard" dewatering test mentioned earlier (100 psi for 1.0 hr) was used as a means of comparing the dewatering characteristics of untreated and treated milfoil. The heat treatment is seen to increase dewatering by approximately 85%. Additional discussion of blanching has been reported (9), and further work will be reported in subsequent publications.

TABLE 3. HEAT TREATMENT OF EURASIAN WATERMILFOIL AS A PRETREATMENT FOR THE REMOVAL OF CELLULAR MOISTURE. STANDARD DEWATERING TEST (1 HR AT 100 PSI) USED AS A MEANS OF COMPARISON.

Treatment	Initial moisture of blanched Eurasian watermilfoil (%)	Final moisture of pressed residue (%)	Initial moisture removed (%)	Dry matter in expressed liquid (%)	Chemical oxygen demand of expressed liquid (ppm)
Control	93.5	88.9	44.32	0.39	1,737
Water (2 min at 212 F)	92.5	73.0	78.10	0.64	2,828
Water (3 min at 212 F)	93.6	71.4	82.9	0.92	5,171
Steam (2 min at 212 F)	93.1	70.7	82.1	1.51	6,141
Steam (3 min at 212 F)	93.7	71.8	82.9	0.93	6,464

UTILIZATION AND DISPOSAL STUDIES

At present, a significant part of the cost of mechanical aquatic plant management is the disposal of the harvested plant material. Frequently this is trucked unprocessed to land fill sites a considerable distance from the harvesting site. If, instead of adding to the cost of aquatic plant management, the harvested plant material could be profitably utilized, the economics of the whole process would be greatly improved.

The composition of Eurasian watermilfoil has been fairly well documented (2, 11). With occasional exceptions, crude protein runs 20 to 25%, xanthophylls 650 to 1100 ppm, and crude fiber 10 to 12%, all on a dry matter basis. These figures show Eurasian watermilfoil as approximately equal to alfalfa (*Medicago sativa* L.) in protein content and superior to it in xanthophyll content. The effectiveness of some xanthophylls in pigmenting egg yolks has been reported (6).

Terrestrial plants vary greatly in their nutritional value with the stage of physiological maturity. The fairly wide ranges given for the various constituents of aquatic plants indicate that they too have this characteristic. The effect is somewhat complicated in Eurasian watermilfoil by the fact that it has a long central stem with varying stages of maturity along the stem. This indicates the need for studying the optimum time interval and depth of harvesting for a maximum sustained yield of nutrients.

A major deterrent to the utilization of aquatic vegetation for livestock feed or other purposes is its moisture content of about 90%. This means that for every pound of dry matter, at least 10 pounds of harvested material has to be handled and transported. For this reason, some degree of mechanical dewatering appears to be a logical early step in any handling, processing, utilization, or disposal sequence.

Figure 8 shows a number of alternative procedures which are receiving consideration for utilization or disposal of harvested aquatic vegetation. These are discussed briefly below, and Koegel, *et al.* (9) provide a more complete discussion.

Domestic animals do not normally relish watermilfoil vegetation in the as-harvested condition. Therefore, if it were desired to feed it directly, some minimal processing to improve palatability would probably be necessary. In preliminary work it has been noted that a heat treatment seems to improve palatability, presumably by driving off some undesirable volatiles. Fermentation to a silage might serve the dual purpose of preserving the material while improving palatability. Combining the aquatic vegetation with terrestrial forage plants or with other additives, or using both of these additions offers the possibility of modifying the nutrient content and palatability of the harvested aquatic vegetation. Preliminary tests indicate that since aquatic plants contain an entirely different flora of microorganisms than terrestrial plants, it may be necessary to pasteurize the aquatic vegetation and then reinoculate it with organisms which will give a desirable fermentation.

Following initial dewatering and chopping, fractionation has been used by the authors to divide the plant material into a juice fraction and a fibrous fraction. A protein and mineral concentrate may be made from the juice fraction and the fibrous fraction either disposed of or used as animal feed. The protein concentrates may have potential for use in human nutrition as well as for animal nutrition. The protein concentrate or the fibrous fraction might be used for fish production in addition to livestock feeding. Protein concentrates made by fractionation of green alfalfa are also being studied by University of Wisconsin researchers (10, 13).

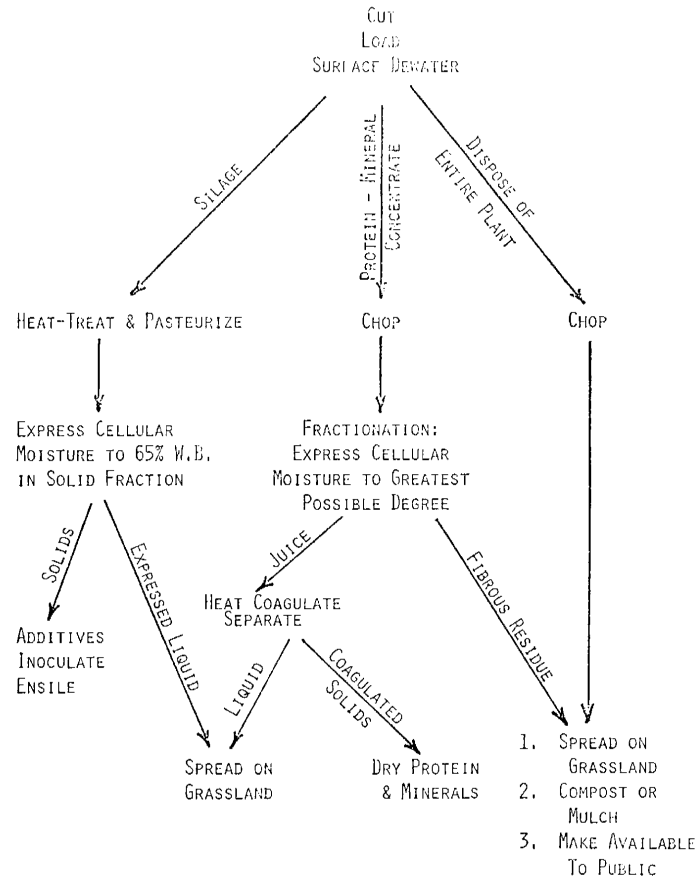

Figure 8. Alternate processing paths for aquatic vegetation.

The authors have demonstrated that large quantities of the chopped, partially dewatered plant material may be disposed of by spreading on lawns or agricultural land using conventional agricultural spreaders, with no negative effects (Figure 9). Given a near maximum harvest, it is estimated that about 1/3 acre of lawn is needed per acre of lake area on a given day. However, it appears that material could be spread on the same area many times during the growing season, thus reducing greatly the ratio of spreading area to lake area. The authors have also used the partially dewatered, chopped vegetation for mulching, compost, and other soil conditioning functions on a small scale with good success. Interest displayed by the urban public in the chopped, partially dewatered vegetation as a soil conditioner gives credence to the belief that a large quantity, if not all, of the vegetation could be disposed of by simply making it available to the public at dockside.

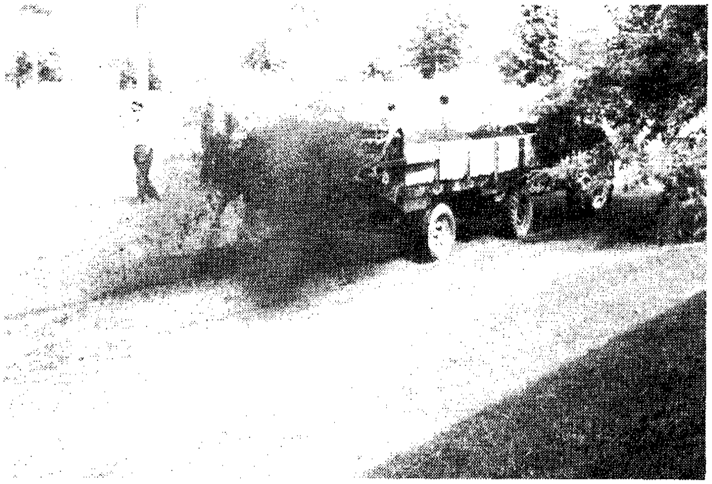

Figure 9. Spreading chopped, dewatered aquatic vegetation on a lawn.

CONCLUSION

Results of processing research to date appear to offer considerable potential for drastically improving the economics of disposal, or utilization of harvested aquatic vegetation, or both. A second phase of this research program is concentrating on efforts to increase harvesting rates. Present aquatic plant harvesters have the capability of covering approximately 1.0 acre per hr, only a small fraction of the rate at which analogous agricultural harvesting operations are carried out. Reasonable success in research efforts aimed at increasing harvesting rates should allow harvesting and processing systems which can be both effective and economical in the management of nuisance aquatic vegetation.

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