

Growing *Makaloa* (*Cyperus laevigatus* L.) in Constructed Wetlands for Weaving and Treating Wastewater

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INTRODUCTION

This study brings together the needs and interests of wastewater managers and traditional artisans in Hawai'i.

In a project supported by the Native Hawaiian Culture and Arts Program (NHCAP), Bishop Museum staff members from the Amy B.H. Greenwell Ethnobotanical garden were working with Native Hawaiian weavers to support a revival of the lost art of weaving *makaloa*, *Cyperus laevigatus* L. A persistent obstacle to the revival has been the shortage of culms of sufficient length to be useful for weaving, and their relative inaccessibility to the general public.

At the same time, members of the constructed wetlands research team of the Midcontinent Ecological Science Center, an office of the U.S. Geological Survey, Biological Resources Division, headquartered in Ft. Collins, Colorado, were interested in the application of treatment wetlands to some of the wastewater management challenges that now face Hawai'i. The treatment performance of native Hawaiian wetland plants remains largely unstudied. Could a treatment wetlands utilizing *Cyperus laevigatus* help reclaim wastewater and supply traditional artisans at the same time?

Makaloa Mats

“The finest sleeping mats in Polynesia...” said Peter Buck (1957:132) of the woven products once made from *makaloa*. Ni'ihau, a small island near Kaua'i, was famous above all for its *makaloa* mats, and the mats were much sought after by Hawaiian chiefs and later foreign visitors.

By the end of the 19th century Hawaiians were no longer weaving *makaloa*, for a number of reasons including population loss, cultural and economic changes, and environmental changes on the island of Ni'ihau. In 1993, the Native Hawaiian Culture and Arts Program began a project based at the Bishop Museum Amy B.H. Greenwell Ethnobotanical Garden on Hawai'i Island to support the revival of the tradition through

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Fig. 1. Unfinished *makaloa* mat. A 6" ruler for scale is visible along the top edge of the mat. (Bishop Museum photo CA 2558.)

some basic research. Hawaiian pandanus weaver Elizabeth Maluihi Lee began to relearn the techniques and within a few years had mastered them sufficiently to weave a number of mats, and she began teaching workshops and training apprentices.

One early photograph of a mat in progress (Fig. 1) shows culms after trimming of approximately 100 cm, and an informant who was alive during the late 19th century says that culms might reach one or two fathoms (Kapaka 1959)—which by a conservative reading is equivalent to one or two meters. While *makaloa* is still abundant in coastal wetlands on Maui and Hawai'i, the culms are generally too short to be useful as weaving stock. Most culms of *makaloa* now growing in Hawai'i fall within 10-45 cm, but as Elizabeth Lee found, about 90 cm is the lower limit for culm length of useable weaving stock for mat making.

Only at one site, in Kanahā Wildlife Sanctuary on Maui, are culms of suitable length for weaving in abundant supply (Fetters and Van Dyke 1996). The Hawai'i State Department of Land and Natural Resources, which administers the sanctuary, allowed Elizabeth Lee to collect weaving stock from the site for research purposes, but the general public does not have access to this single source of long *makaloa* culms.

Municipal Wastewater in Kailua-Kona

West Hawai'i is situated on the leeward side of the slopes of three large volcanoes, Mauna Kea, Hualalai, and Mauna Loa. It has a population that is growing rapidly, while infrastructure improvements lag behind. Municipal wastewater from the principal population center, Kailua-Kona and the surrounding area, is treated at the Kealakehe Wastewater Treatment Plant, an aerated lagoon system which is running at about 20% of its design capacity, and producing approximately 1 million gallons per day of secondary treated wastewater. Much other wastewater in the community is still treated by septic tanks.

Before the effluent leaves the treatment system, it is chlorinated. Approximately 30,000 gpd is reused by a nearby driving range. The remaining effluent is piped approximately 1 km upslope from the treatment plant and infiltrated into the ground.

The County of Hawai'i is exploring the possibility of switching from chlorination to an ultraviolet disinfection system. The cost of ultraviolet disinfection is closely linked to the turbidity of the water to be treated. A treatment wetlands would be a low cost method of reducing suspended solids, and thus turbidity, thereby facilitating the switch to ultraviolet disinfection. Also, treatment wetlands would mitigate the possibility of pollution by nutrient rich treated wastewater of groundwater or near shore coral reef communities.

MATERIALS AND METHODS

This experiment looks at the feasibility of growing *Cyperus laevigatus* and harvesting culms for weavers in a multipurpose treatment wetlands. A subsurface flow wetland mesocosm facility was set up on the campus of West Hawai'i Explorations Academy, to which water was brought for system influent from the nearby Kealakehe Wastewater Treatment Plant. Nutrient, total suspended solids, and fecal coliform concentrations were measured in the system influent and effluent, and the effects of alternate harvesting regimes on treatment performance were studied.

The research questions addressed by this study were the following:

1. Is *Cyperus laevigatus* a good candidate species for subsurface flow treatment wetlands in Hawai'i, in terms of treatment performance and horticultural suitability?
2. How will harvesting affect the treatment performance of *Cyperus laevigatus*?
3. Is it possible to grow weaving length (90cm+) culms of *Cyperus laevigatus* in a subsurface flow treatment wetlands using municipal wastewater?

In March and April of 1998, five experimental wetland cells (Fig. 2) were constructed at the West Hawai'i Explorations Academy (WHEA) near Keahole Point on the west side of the island of Hawai'i (19°43'13"N, 156°03'17"W). The cells were 1.5 x .4 x .4 m deep and lined with high density polyethylene. The cells were filled to .3 m with #3 crushed basalt (particle size ¼"-¾", with no fines). The bottoms of the cells sloped 2.5 cm toward the south end, where a drain was fitted at the bottom of each cell.

The cells were supplied with water from a nearby elevated holding tank with a capacity of approximately 2,270 liters. The outflow from the tank was controlled by a battery operated electronic valve and flowed through the valve to a splitter box which distributed the flow to each of the five cells through polyethylene tubing.



Fig. 2. The experimental set up at WHEA. In the background is the elevated holding tank for system influent. Five cells (one unvegetated) are visible in the foreground

On February 2, 1998, a nursery was established at WHEA to grow seedling makaloa plants for transplanting into the cells. The seedlings were started in 3.5" nursery containers in a medium of Sunshine #5 (a peat based commercial plug mix), with 5 g 15-11-13 Sierra 3-4 month coated fertilizer incorporated per liter of medium. 3-4 seeded spikelets were pulverized and sprinkled on the top of each container, covered lightly and pressed down with a block of wood.

The first sprouts emerged on February 11, 1998, and on April 18, they were planted into the cells. By then the containers were well filled with plants, the tallest culms averaging about 25 cm, some of them flowering. The plants were removed from the containers and planted without separating them into individual plants, so that the contents of each container was treated as a single plug. They were planted into the cells three plugs wide by ten plugs along the length, so that the root crowns of the plants were at the level of the top of the rocks.

Table 1. Analysis of tap water from West Hawai'i Explorations Academy (WHEA)
AECOS Laboratory of Hawai'i. 2/11/98

Analyte (unit)	
pH	7.8
Hardness (mg/L)	144.7
Bicarbonate (mg/L)	ND
Carbonate (mg/L)	ND
Electrical Conductivity (umhos/cm)	928
Total Dissolved Solids (mg/L)	640
Sodium (mg/L)	5.43
Chlorides (mg/L)	247
Boron (mg/L)	0.06
Nitrate-Nitrogen (mg/L)	1.12
Phosphate (mg/L)	0.01
Potassium (mg/L)	6.30
Magnesium (mg/L)	21.8
Calcium (mg/L)	22.0
Sulfate (mg/L)	73.0
Manganese (mg/L)	0.01
Iron (mg/L)	0.01
Ammonia Nitrogen (mg/L)	0.002
Total Nitrogen (mg/L)	1.41

The cells were filled with water to approximately 2 cm below the level of the top of the rocks. An average of 54 liters of liquid was required to fill each cell to that level. From April 18 until May 7, 1998, the cells were kept filled with tap water (Table 1) and on May 7, 1998, the holding tank was filled with water drawn from Lagoon 6, the final treatment lagoon at the Kealakehe Water Quality Control Plant.

The electronic valve was set so that the flow of water was metered into the cells twice daily, such that the total flow to each cell was approximately 18 liters per day. This amounts to a total retention time of 3 days.

From May 7, 1998, through September 27, 2000, the cells were monitored frequently by students at WHEA, and visited approximately once every two weeks by staff from Amy Greenwell Garden. On these biweekly visits, the holding tank was resupplied with water from Kealakehe Water Quality Control Plant as needed, the equipment was checked and minor repairs made as necessary, and the plants were photographed. *Bacillus thuringiensis* ssp. *israelensis* cakes were added to the holding tank every month to control mosquito populations.

Water samples were taken from the holding tank, which represented the system influent and from each of the cells (the system effluent) approximately once every four weeks. From May 26, 1998 (the date of the first solution samples from the cells) through April 27, 1999, the latter samples were taken by lowering the drain below the level of the water in the cells and collecting the fluid as it exited the drain. From May 24, 1999 through September 27, 2000, the samples were taken by opening the valve from the

holding tank to raise the level of fluid in the cells and catching the solution as it overflowed through the drains.

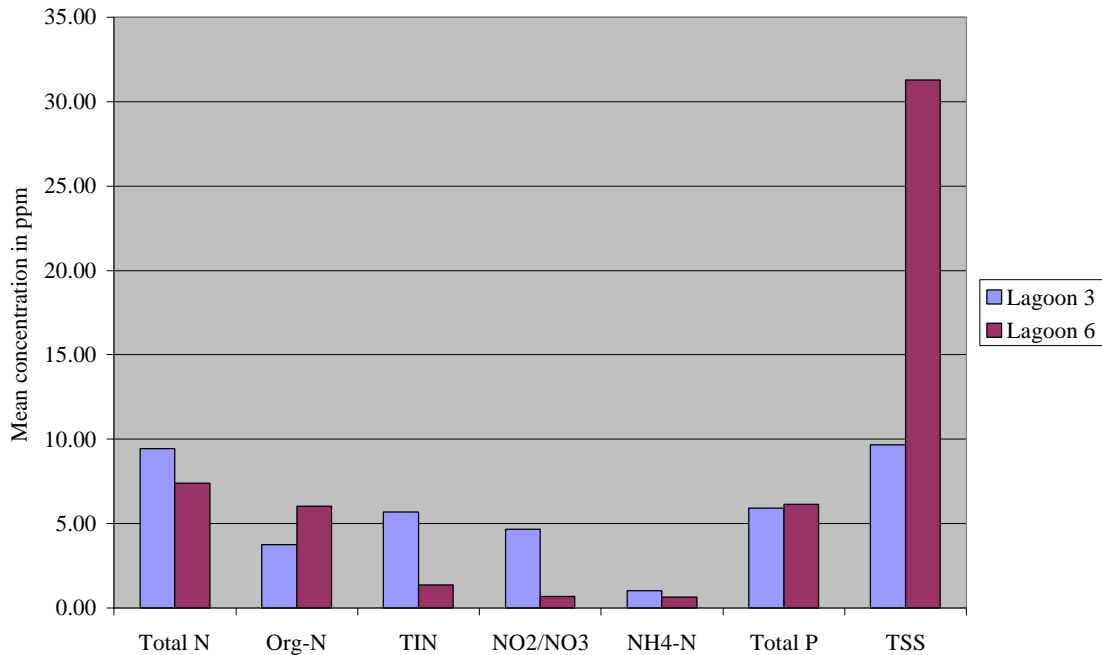
These samples were analyzed by the University of Hawai'i Agricultural Diagnostic Service for total nitrogen, total phosphorous, nitrite nitrogen, nitrate nitrogen, and ammonium nitrogen. Another set of samples was analyzed by the laboratory technicians at the Kealakehe Wastewater Treatment Plant for fecal coliforms and total suspended solids.

The test of alternate harvesting regimes was conducted during the first year of the experiment. On July 27, 1998, October 26, 1998, January 26, 1999, and April 27, 1999, four of the cells were harvested. On the first three dates, Cells 1 and 4 were harvested by pulling the culms as a weaver might pull them when she harvested makaloa for weaving stock, in such a way to result in removal of approximately ten percent of the total above ground biomass, with the tallest culms being selected for removal. Cells 2 and 5 were harvested by cutting all the culms in a cell approximately 10 cm above the base, simulating the effect of mowing. Cell 3 was left as an unharvested control during this phase of the experiment. On April 27, 1999, all five of the cells were harvested by cutting approximately 4 cm above the surface of the rock, including Cell 3. The harvested material from each cell was weighed, and samples of the culms were sent for tissue analysis and dry matter analysis. The tissue analysis returns results for nitrogen, phosphorous, potassium, calcium, magnesium, sodium, manganese, iron, copper, zinc, and boron.

From April 27, 1999 through September 27, 2000, a revised regime of harvesting and sampling was continued. All of the *Cyperus laevigatus* was removed from Cell 4, the crushed rock substrate were removed, the lining was washed to remove plant debris, and the cell was refilled to approximately 30 cm with fresh crushed rock. That cell was left unvegetated with rock only as a control. Cells 1, 2, and 5 were not harvested on a regular schedule, but rather an attempt was made to match the harvest schedule with the natural life cycle of the plant. On May 1, 2000, when senescence had begun to outpace growth cells 1, 2, and 5 were harvested by cutting. Cell 3 was left unharvested until the end of the second phase of the experiment on September 27, 2000, when it was harvested by cutting along with the other three vegetated cells for the final time.

Solution sampling and analysis remained on the same schedule as described in the original. Tissue sampling and analysis were conducted at the times of harvest. In addition, from May 26, 1998, to April 27, 1999, the system influent was collected from Lagoon 6 at the Kealakehe Wastewater Treatment Plant, which is the final lagoon in the treatment cycle at that plant. From April 27, 1999, through September 27, 2000, the system influent was collected from Lagoon 3 at the treatment facility. Lagoon 3 is earlier in the treatment cycle. Water from Lagoon 3 has more inorganic nitrogen and less suspended solids than water from Lagoon 6 (Chart 1).

Chart 1. Influent concentrations



RESULTS

1. Is *Cyperus laevigatus* a good candidate species for subsurface flow treatment wetlands in Hawai'i, in terms of treatment performance and horticultural suitability?

Cyperus laevigatus is a good candidate species for subsurface flow treatment wetlands in Hawai'i. It performed well at removing nutrients from wastewater, particularly inorganic nitrogen, and it is easily grown in a subsurface flow environment.

Treatment performance

The removal efficiency (RE) for nitrogen in vegetated cells for the entire study was 44.34% (Table 2). Vegetated cells performed better at removing inorganic nitrogen (80.16%) than organic nitrogen (20.43%). In Lagoon 3, which is earlier in the treatment cycle at the treatment facility, relatively more of the total nitrogen is in the inorganic form than it is in Lagoon 6. Consequently, the total nitrogen RE during Phase 2 (51.24%), which drew from Lagoon 3, was higher than during Phase 1 (34.06%), which drew from Lagoon 6. However, the effluent concentration of total nitrogen remained about the same during both phases (4.87 ppm in Phase 1, 4.57 ppm in Phase 2).

The phosphorous RE for vegetated cells remained low throughout the study (7.53%). The effluent concentration of phosphorous was similar throughout the study (5.86 ppm in Phase 1, 5.00 ppm in Phase 2, and 5.27 ppm for the non-vegetated cell)

The mean concentration RE of total suspended solids (TSS) throughout the study was 49.85%. However, this RE varied greatly from Phase 1 (70.32%) to Phase 2 (-5.32%). The effluent concentration of TSS during both phases was about the same (9.29 ppm in Phase 1, 10.28 ppm in Phase 2). This concentration is nearly within the range (1-10 mg/L) identified by Kadlec (2000) as the background concentration for TSS in subsurface flow constructed wetlands; that is, the concentration below which such wetlands cannot be expected to remove TSS. The mean concentration of TSS in Lagoon 6 was higher than in Lagoon 3, so that bringing it down to background resulted in a higher RE in Phase 1 than in Phase 2, when the influent concentration was already at the background concentration.

During Phase 2, the mean concentration RE for total inorganic nitrogen (TIN) was 80.60% in the vegetated cells versus -9.17% in the unvegetated cell. Plant uptake was probably responsible for removal of inorganic nitrogen from the wastewater.

The mean concentration RE for organic nitrogen during the Phase 2 was 16.63% in the vegetated cells, while in the unvegetated cell the mean RE was 46.83%. This may be accounted for by the additional organic matter produced in the vegetated cells by the plants themselves, some of which is shed into the surrounding medium. As organic nitrogen is converted into inorganic nitrogen through decomposition and nitrification, it is removed by plant uptake in the vegetated cells, resulting in a lower mean concentration of total nitrogen in effluent from vegetated cells (4.57 ppm) than from the unvegetated cell (7.82 ppm), where the inorganic nitrogen is not removed

The mean concentration of phosphorous in both cases was about the same (5.00 ppm in vegetated cells, 5.27 ppm in the unvegetated cell). Phosphorous was probably removed by mechanical filtering of particulates.

Vegetated cells were reducing the concentration of TSS—starting with background concentrations—at a mean RE of -5.32%, compared to -77.01% for the unvegetated cell. The better performance of the vegetated cells may be due to the presence of sloughed off biofilms in the unvegetated cell samples, increased pore space provided by the presence of roots and rhizomes in the gravel bed (and hence less clogging and flow short-circuiting), or by better retention of solids by the mat of roots and rhizomes.

Fecal coliforms were also counted during the study on a total of 16 occasions (Table 3), with inconclusive results. Of the 80 measured effluent counts, 16 (20%) showed greater concentrations of colonies for the effluent than the concentration measured for the influent at the same time. It is important to note that the coliform counts of influent and effluent taken at the same time do not truly track the process: the influent counts coliforms in water that has not actually been introduced to the system at the time the effluent is sampled, and the effluent coliform count is the result of a presumed residence of three days in the system. 48 effluent counts (60%) were 1 or fewer colonies per hundred milliliters.

Table 2. Summary of treatment performance

Period	Mean values	Total nitrogen	Organic nitrogen	Total inorganic nitrogen	Combined NO2/NO3 nitrogen	Ammonium nitrogen	Total phosphorus	Total suspended solids
Vegetated cells Entire study 7 May 1998- 27 Sep 2000	Mass influent load mg/m ² /day	260.21	263.25	265.92	267.49	262.41	263.19	268.23
	Influent concentration ppm	8.47	5.08	3.39	2.64	0.76	5.86	19.43
	Effluent concentration ppm	4.71	4.04	0.67	0.29	0.38	5.42	9.74
	Concentration RE	44.34%	20.43%	80.14%	88.88%	49.68%	7.53%	49.85%
Vegetated cells Phase 1 7 May 1998- 27 Apr 1999 Lagoon 6	Mass influent load mg/m ² /day	226.75	185.24	41.52	21.00	20.52	188.38	960.99
	Influent concentration ppm	7.38	6.03	1.35	0.68	0.67	6.13	31.29
	Effluent concentration ppm	4.87	4.52	0.35	0.10	0.25	5.86	9.29
	Concentration RE	34.06%	25.07%	74.16%	85.80%	62.24%	4.49%	70.32%
Vegetated Cells Phase 2 5 May 1999- 27 Sep 2000 Lagoon 3	Mass influent load mg/m ² /day	287.76	131.88	155.88	130.37	25.51	173.13	318.69
	Influent concentration ppm	9.37	4.29	5.07	4.24	0.83	5.64	9.67
	Effluent concentration ppm	4.57	3.58	0.98	0.48	0.50	5.00	10.18
	Concentration RE	51.24%	16.53%	80.60%	88.68%	39.31%	11.29%	-5.32%
Unvegetated cell: Phase 2 5 May 1999- 27 Sep 2000 Lagoon 3	Mass influent load mg/m ² /day	287.76	131.88	155.88	130.37	25.51	173.13	318.69
	Influent concentration ppm	9.37	4.29	5.07	4.24	0.83	5.64	9.67
	Effluent concentration ppm	7.82	2.28	5.54	4.90	0.64	5.27	17.11
	Concentration RE	16.50%	46.83%	-9.17%	-15.47%	23.02%	6.56%	-77.01%

Table 3. Fecal coliform colonies per 100 ml

Cell Number	1	2	3	4	5	Influent
8/25/98	1	1	25	1	1	1
9/22/98	1	10	1	40	30	1
10/26/98	1	1	1	1	1	2
11/17/98	1	1	1	1	1	17
12/17/98	1	1	1	1	1	1
1/26/99	1	1	1	1	1	1
3/23/99	1	1	1	16	1	153
5/24/99	89	2	1	1	1	9
10/26/99	1	260	35	200	1	20
2/1/00	26	70	42	45	18	182
2/29/00	3	38	10	109	2	tntc*
4/25/00	175	300	1	120	80	20
5/24/00	1	300	56	4	1	36
6/21/00	1	27	1	1	1	1
8/15/00	1	1	1	1	2	13
9/27/00	2	350	6	1	1	1

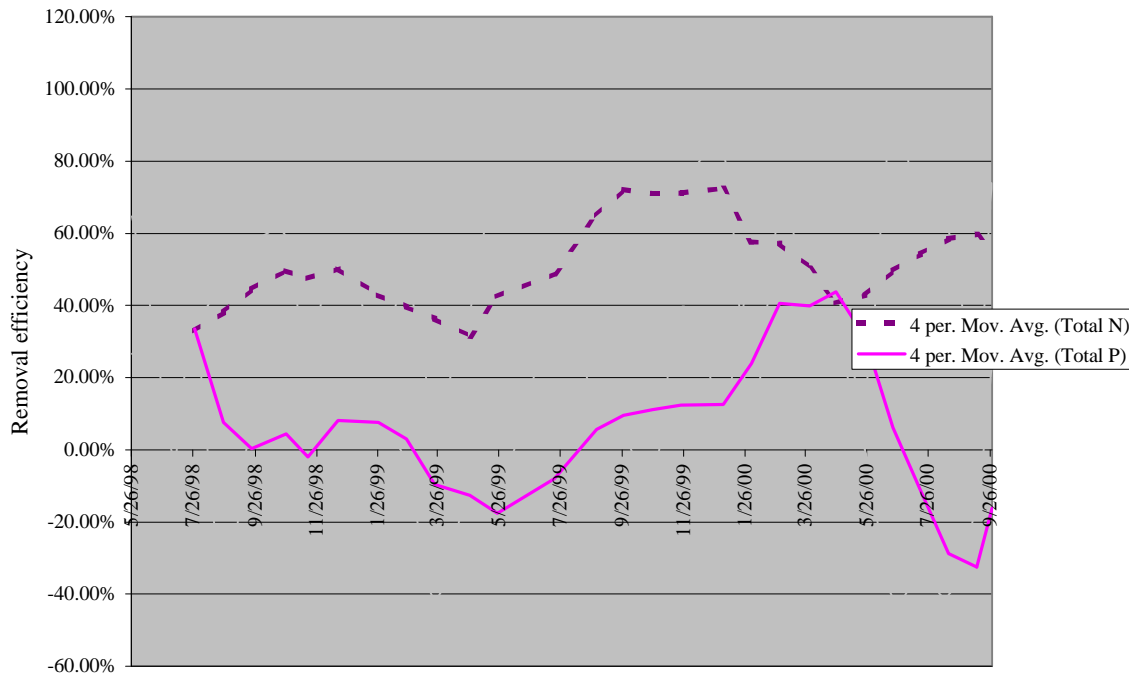
Horticultural suitability.

Cyperus laevigatus grows readily in cultivation. Seeds sprouted within 10 days of sowing, and seedlings were ready for transplanting within two months. Plugs grew rapidly, reaching maximum growth within 5 months after setting out.

Cyperus laevigatus displayed cyclic die back and regrowth during this experiment and the previous experiment (Fetters and Van Dyke 1998). The cause of this is unknown. Some cells were affected earlier and more severely, but all showed some signs of die back. Regeneration was from both new culms sprouting from existing rhizomes and natural reseeding. Die off started in October, 1998 and reached a peak by May, 1999. A second incident of die off peaked in May, 2000. After a May harvest, the cells regrew vigorously, but by the end of the experiment in September, 2000, it was apparent that another die back was underway. Chart 2 uses a moving average to display the relationship between the periods of die off and mean RE of total nitrogen and total phosphorous in all vegetated cells. Removal of total nitrogen appears to track the die off periods, with a decline in efficiency bottoming in April and May of 1999 followed by a rise in efficiency during the following months, and another decline during April and May of 2000 followed by another rise in efficiency during the following months.

* too numerous to count

Chart 2. Efficiency trends over time



2. How will harvesting affect the treatment performance of *Cyperus laevigatus*?

During Phase 1 (May 7, 1998-April 27, 1999), three alternate regimes of harvesting were tested in order to assess their effects on treatment performance. Weavers normally harvest makaloa by selectively pulling the tallest culms, and this method was tested in two of the cells. Subsurface flow wetlands can be mechanically harvested, mowed by a tractor or power cutter that is driven over the firm surface of the gravel bed. Two more cells were harvested to simulate mechanical harvesting. A final cell was left unharvested as a control. There were no appreciable differences in treatment performance among the three harvest regimes (Chart 3). It is reasonable to assume from these data that *Cyperus laevigatus* could be harvested up to several times a year from a treatment wetland without affecting removal efficiency.

Biomass removal is a way of removing nutrients from the system. If left in the treatment wetland, decaying biomass will eventually return nutrients to the water. The harvesting experiment returned information on the relative biomass removal potential of harvesting four times a year through cutting or pulling, and harvesting once a year by cutting (Chart 4).

Chart 3. Comparing harvest methods

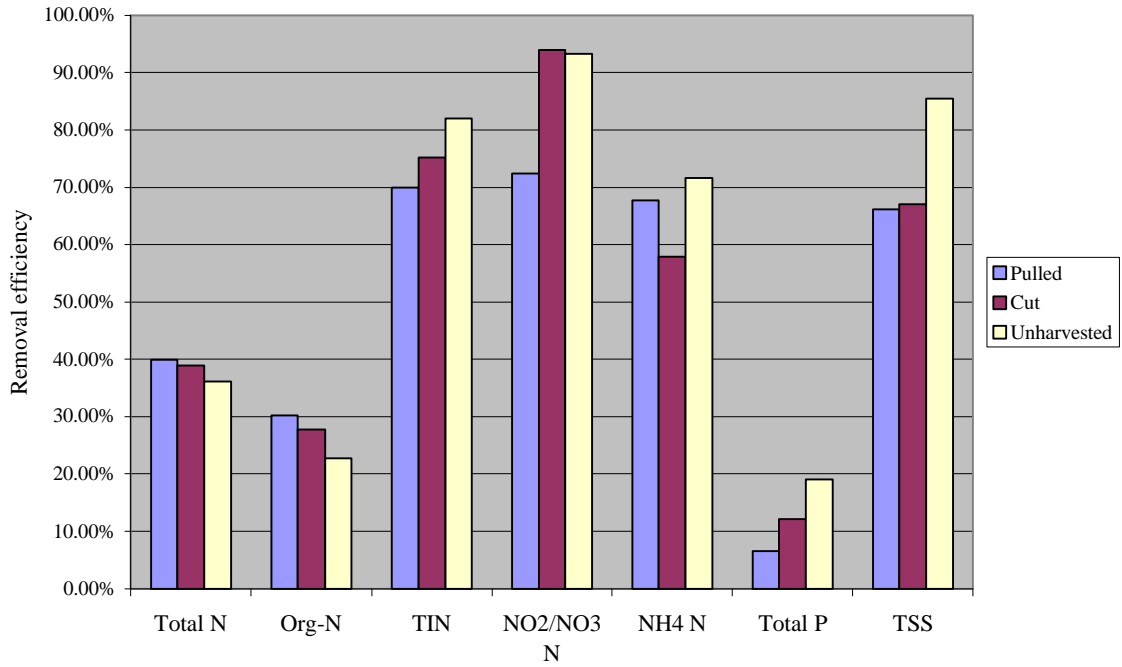
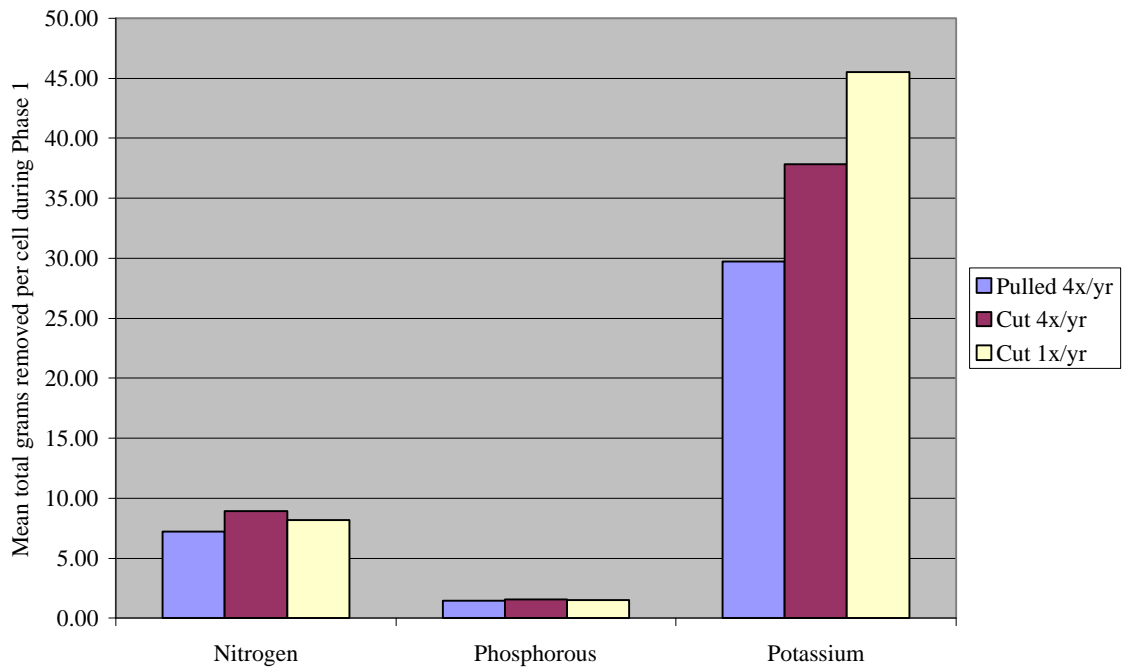


Chart 4. Biomass removal



There were no appreciable differences in total mass of the three major nutrients removed, either from method or frequency of harvesting. It would appear that there is no advantage as far as biomass removal from harvesting more than once a year—nor is there any disadvantage to more frequent harvesting. Above ground biomass was removed by harvesting from this mesocosm at a mean rate of 135 kg nitrogen, 25 kg phosphorous, and 628 kg potassium per hectare during the first year of the experiment. During the second year, above ground biomass was removed at a mean rate of 154 kg nitrogen, 30 kg phosphorous, and 510 kg potassium per hectare. The experiment ran 149 days into the third year, and the extrapolated annual above ground biomass removal rate for the third year was 215 kg nitrogen per hectare, 42 kg phosphorous, and 407 kg potassium.

3. Is it possible to grow weaving length (90cm+) culms of *Cyperus laevigatus* in a subsurface flow treatment wetlands using municipal wastewater?

This question was answered early in the experiment. In the unharvested cell (Cell 3) by September 22, 1998, many of the culms at the influent end of the cell were between 90 and 100 cm, with some over 100 cm. This is long enough to be suitable as weaving stock.

However, the first harvest of the other cells came on August 28, 1998, and subsequent harvests followed at three month intervals. This schedule did not allow weaving length makaloa culms to grow in the harvested cells during the first year. Timing of harvesting will obviously be important when supplying weavers.

Nor did weaving length makaloa culms appear in any of the cells during the second year of the trial, in spite of the fact that total inorganic nitrogen concentrations were increased during the second year by taking waste water from earlier in the treatment cycle as system influent. What caused the subsequent decline in maximum culm length remains unknown. It could be related to the age of the plant, some pathological agent, crowding in the mesocosm, or insufficient nutrient levels in the wastewater for sustained growth of tall culms.

These factors aside, there was still an apparent correlation between nutrient concentration and culm length. That is, within a cell at any given time, the tallest culms were invariably at the influent end of the cell, and the culm height decreased toward the effluent end (Fig. 3). This was true for all vegetated cells throughout the two years of the experiment. The plants near the influent may have been taller because they had more access to nutrients; they removed nutrients from the water before it flowed past them, leaving less nutrients available for plants downstream.

DISCUSSION

A treatment wetlands could be added to the process at the Kealakehe Wastewater Treatment Plant after Lagoon 3 or after Lagoon 6 with approximately the same results. In both cases the product of the wetland system was approximately the same as far as concentration of nutrients and suspended solids. The treatment performance is related to the initial concentration of TSS and nutrients. When TSS concentrations are higher,



Fig. 3. Culm heights were greater at the influent end of all the vegetated cells.

the wetlands removes more TSS. When nutrient concentrations are higher, the wetlands removes more nutrients.

Thus if a treatment wetland is added to the current system after five treatment lagoons at Kealakehe, it will initially be most effective at removing suspended solids, the concentration of which is relatively higher due to the current levels of algae in the final lagoon. By the time the plant is operating at full capacity, the quality of the final effluent of the aerated lagoon treatment will probably be more like the water currently in Lagoon 3 than that currently in Lagoon 6, with relatively higher concentrations of inorganic nitrogen, less algae, and lower TSS concentrations. A wetland polishing stage will be removing more nutrients from the water and less suspended solids than it did when the system was operating below capacity.

A subsurface flow wetland cell with a greater width to length ratio will remove more nutrients than a cell that is relatively longer than wider. The plants near the influent end of these subsurface flow mesocosms appeared to be taking up most of the nutrients. As the width of the cell increases in proportion to the length, so does the proportion of plants in the cell close to the influent end increase.

While this study looked at the treatment performance of *Cyperus laevigatus* only, it would be good to include a variety of different wetland plant species in a treatment wetland. *Cyperus laevigatus* is subject to periodic die backs, with some apparent effect on treatment performance. Growing a variety of wetland species might help offset this tendency.

Other native wetland plants that should be considered include ‘*ahu‘awa* (*Mariscus javanicus* (Houtt.) Merr. & Metcalfe), *kaluhä* (*Bolboshoenus maritimus* (L.) Palla), ‘*aka‘akai* (*Schoenoplectus lacustris* subsp. *validus* (L.) Palla), and *kohekohe* (*Eleocharis calva* Torr.)

Weavers could decide the methods and schedule of harvesting *makaloa* without jeopardizing the treatment performance of a constructed wetland. None of the harvest regimes or schedules in this experiment had an appreciable effect on treatment performance. As weavers trim the bottom portion of the culms before using, even periodic mechanical harvesting for biomass removal would be compatible with reuse by weavers.

While the demand for *makaloa* culms for weaving is small and likely to remain so, a treatment wetlands that produced weaving length culms would be a great service to the weaving community. Furthermore, using *makaloa* and other native wetland plants with traditional applications in a treatment wetlands will generate interest in the process of treating wastewater among traditional artisans and students of traditional Hawaiian culture.

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