Processing And Storage Of Waterhyacinth Silage[1,2]

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ABSTRACT

Waterhyacinth (*Eichhornia crassipes* (Mart) Solms) was satisfactorily ensiled by chopping, pressing in a screw press to less than 90% moisture content, mixing with a free carbohydrate additive, and packing in small silos. Chopped waterhyacinth without pressing putrefies and shrinks excessively. Additional carbohydrate is necessary in most cases to cause fermentation to acceptable silage. Dried citrus pulp or cracked corn at 4% of the wet weight (20 to 25% of the dry weight) were found to be satisfactory carbohydrate sources, 2% being slightly less satisfactory. Quality of silage was unaffected by the addition of 0.5 or 1.0% standard cane molasses.

INTRODUCTION

Utilization of aquatic plants has been proposed and investigated as an alternative to destruction as a method of control. Taylor (12) evaluated waterhyacinth as a source of high quality protein. Nolan[3] has investigated paper making qualities of waterhyacinth fiber. Parra and Hortenstine[4] explored use of waterhyacinth as a soil additive. Two private operators are manufacturing horticultural potting media based on partially composted waterhyacinth and promoting it for home, commercial, and public use. Bruhn, Livermore, and Abaoba (5) explored a broad range of uses for Eurasian watermilfoil (*Myriophyllum spicatum* L.). Boyd (4) and Shirley, et al. (10) have reported that waterhyacinth and hydrilla (*Hydrilla verticillata* Royle) are chemically suitable as animal feeds.

Hentges (8) and Combs (7) fed dried waterhyacinth and hydrilla to beef and swine and found quality and acceptance to be variable and utilization to be marginal to inadequate. In early trials, hydrilla was found to be more satisfactory than waterhyacinth, but in later trials Salveson (9) and Stephens (11) found waterhyacinth to be better. The differences were attributed to source, in that higher quality waterhyacinth and lower quality hydrilla were used in the later trial.

Bagnall et al. (2) found that in addition to variability due to source, processing could affect the composition and acceptability of feeding materials. Because of the high moisture content (90 to 95%) of aquatic plants, water can be cheaply and quickly removed by pressing; nutrient losses in the press liquor depend on degree of pressing and can be substantial. Moisture in the pressed product is

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[3] Nolan, W. J. and D. W. Kirmse. 1973. The paper making properties of waterhyacinth. Talk presented at the 13th annual Hyacinth Control Society meeting held in New Orleans, La., July 16-18.

[4] Parra, J. V. and C. C. Hortenstine. 1973. Plant nutritional value of dried waterhyacinth. Talk presented at the 13th annual Hyacinth Control Society meeting held in New Orleans, La., July 16-18.

still quite high (80 to 90%), so subsequent thermal dehydration is difficult and costly. Sources of processing variability are aggressiveness of pressing, which affects water and nutrient losses, and drying time and temperature, which affect biological and chemical degradation, acceptability and digestibility.

Ensiling aquatic weeds was proposed because the saving of drying machinery and energy costs, though at least partially offset by higher storage and transportation costs, appeared to be economically advantageous, at least under some circumstances. In developing countries, thermal processing plants and energy to operate them are even more difficult to obtain, so the relative advantage of ensiling should be greater. The existing or impending energy crisis in this country also strengthens the position of ensiling.

The objectives of the engineering phase of this project were to determine to what degree waterhyacinth must be processed and how it must be stored to produce acceptable silage.

METHODS AND MATERIALS

Waterhyacinth was chosen for the ensiling tests in preference to other aquatic weeds because of its availability in Gainesville and its relative ease of harvest. Four sources of waterhyacinth were used for the ensiling tests: (a) the deep water discharge end of Lake Alice on the University of Florida campus where growth was marginal and waterhyacinths were available as they drifted before the wind to the harvesting site, (b) the shallow, marshy inlet end of Lake Alice which was covered with a dense growth of waterhyacinth and other weeds, (c) University sewage plant effluent polishing ponds, which had a dense, uniform growth, and (d) Alachua Sink on Paynes Prairies State Park, which was well nutrified by Gainesville effluent and had a luxuriant crop. The deep-water end of Lake Alice was the principal source. Plants were harvested in all seasons.

Plants were harvested with forks or by conveyor depending on site access and quantity needed. The plants were reduced by crimping or chopping to increase density, improve flow characteristics and increase press production rate. The experimental crimper broke the stems irregularly at approximately 25 mm intervals. The forage harvester was adjusted to chop uniform particle lengths ranging from 10 to 25 mm; length of cut in this range had little effect on production rate, product moisture content, or product texture. The flail chopper installed on the largest harvester cut waterhyacinth into random lengths ranging from 1 to 200 mm; the longer lengths reduced press production, but did not affect other performance parameters.

In all but a few tests, the reduced waterhyacinth was screwpressed to remove 40 to 80% of the water, controllable to some degree by press operating conditions. Two screw presses were used: a mobile 30 cm Vincent screw press used by Casselman, et al. (6) for forage dewatering, and a portable 23 cm press designed and built especially for this and similar applications. Choice of press depended primarily on quantity of material needed for a test.

Configuration of the Vincent screw has been described by Bagnall et al. (2). The press was operated at preset projected discharge pressures of 90, 117 and 152 kN/m^2 and speeds of 15, 28, and 36 rpm. Chopped waterhyacinths was blown or conveyed directly from the chopper to the screw inlet. An auxiliary conveying system and blower carried the pressed waterhyacinth to a silo or truck.

Configuration of a 23 cm screw has been described by Bagnall (3). The press was operated at projected discharge pressures of 76 and 145 kN/m^2 and at 51 rpm. The crimped, chopped, or previously pressed waterhyacinth was hand-fed into the feed hopper. Waterhyacinth was pressed once, twice, or three times to determine effect of moisture content on silage quality; one pressing at 76 kN/m^2 was standard for the first barrel silo test and two pressings at 145 kN/m^2 was standard for subsequent barrel silo tests. The pressed waterhyacinth was collected in fiberglass pans or allowed to fall to the previously cleaned paving.

The waterhyacinth was ensiled by mixing it with a carbohydrate additive and storing it in a sealed or semi-sealed container. Barrels, culverts, and a tower silo were used as containers and dried citrus pulp (DCP), standard cane molasses (SCM), cracked yellow dent corn (YDC), and dried waterhyacinth (DH) were used as additives.

Barrel silos, shown schematically in Figure 1, were made from open-ended 208 1 steel drums with heavy polyethylene liners. The barrels could be easily filled and fairly tightly sealed. They were set on stands so that runoff could be collected and the drains were fitted with adapters to

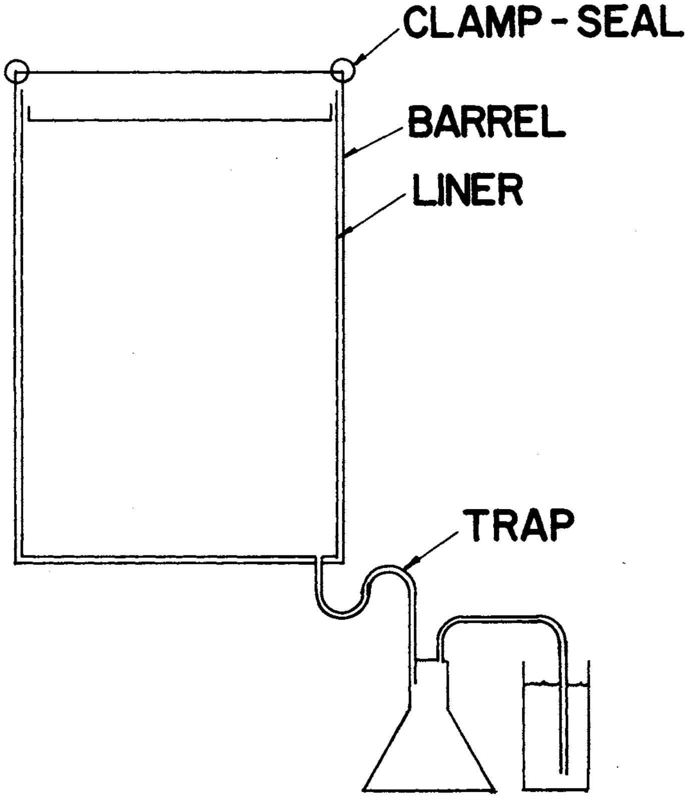

Figure 1. Barrel silo section.

6 mm vinyl tubing. Following an initial test, a runoff collection trap system was installed. The tube from the barrel to a 1000 ml Erlenmeyer flask was looped so that a pocket of runoff fluid would prevent air from traveling up the tube. A line from the collection flask directed displaced air to the bottom of a waterfilled bottle, further preventing air intrusion through the drain line.

Culvert silos, shown schematically in Figure 2, were made from asphalt-coated corrugated steel culvert. The culverts were 122 cm in diameter and 244 cm long and the interior asphalt coating completely filled the corrugations. They were mounted on 1.2-m square wooden pallets with a 1.5 mm steel deck. A 38 mm drain was installed in the center of the deck with a plastic pipe extending to the edge of the pallet. The deck was coated with asphalt to prevent corrosion and the joint between the culvert and deck was sealed internally and externally with 5 cm fillets of asphalt. The end of the drain was stoppered except when runoff measurements or samples were being taken. After the second test, 46-cm square openings were cut in the sides of the silos to aid in removing the silage. The cut-out pieces were reinstalled as doors and sealed with asphalt.

A 3.7 by 12.2 m poured concrete tower silo located at the Purebred Beef Unit was used for the largest scale test.

Free carbohydrate additives were commonly used in grass silages in Florida to improve fermentation and palatability. The most commonly used are dried citrus pulp (DCP) and cane molasses. Three levels of citrus pulp were tested; none, 2% of the pressed waterhyacinth weight, and 4% of the pressed waterhyacinth weight. Standard cane molasses (SCM) was tested at three levels: none, 0.5% of the pressed waterhyacinth weight, and 1.0% of the pressed waterhyacinth weight. Other levels of DCP and SCM were used in a few samples. Because DCP is not available in all areas where waterhyacinth may be ensiled, 2% and 4% cracked yellow dent corn (YDC) was tested as a replacement. To attempt to isolate effects of absorption of free moisture from the effects of added carbohydrates, 4% dried waterhyacinth (DH) was added in place of DCP. Additive combinations tested in the various trials are shown in Table 1.

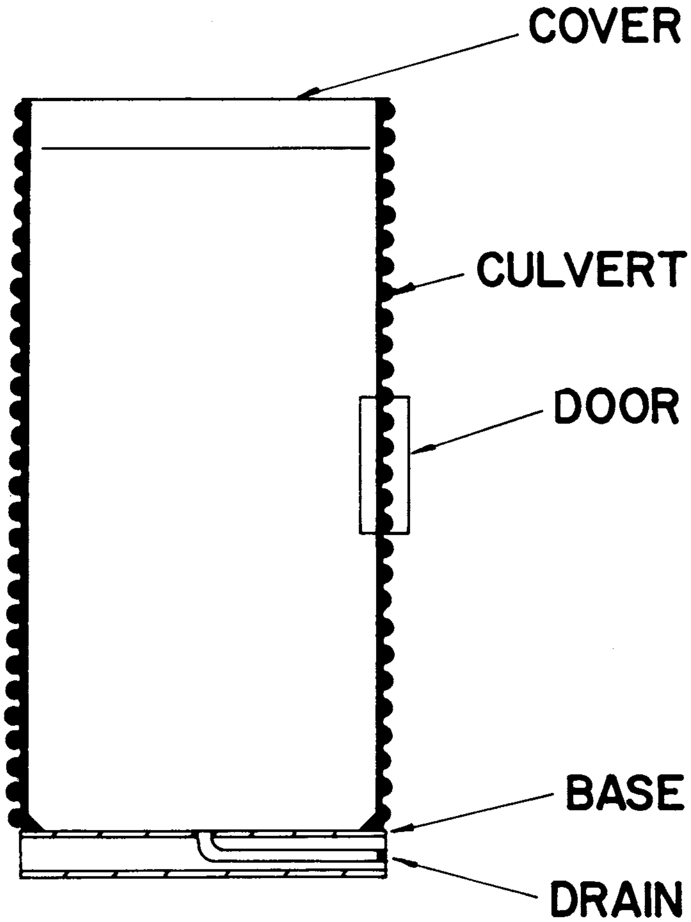

Figure 2. Culvert silo section.

About 100 kg of pressed Lake Alice waterhyacinth and additives were mixed in 10 kg lots and placed in each barrel silo and packed to increase density and exclude air. Waterhyacinth from the polishing pond was used for one test (D in Table 1). The polyethylene cover was then installed, depth measured, and the barrel sealed with its original cover and clamp. The runoff trap was then attached to the drain fitting. The barrels stood in the Agricultural Engineering Laboratory for the predetermined test period.

The culvert silos were filled with waterhyacinth and additives by blowing the material in with the chopper or press blower. Most waterhyacinth was from Lake Alice, but one test (Z in Table 1) used waterhyacinth from the polishing pond and the Lake Alice marsh. Additives were placed in the pressed waterhyacinth in the transfer screw between the press and the blower and were mixed by the screw and blower. The silage was packed by tramping, either after each 230 kg or after the silo was nearly full. Copper-constantan thermocouples were buried 0.9 to 1.2 m below the surface of the silage, either by installing them as the silo was filled or by inserting them with a thin tube after completion of filling and withdrawing the tube. A polyethylene film cover was placed over the silage and tucked in to reduce air diffusion and spoilage. A sheet metal rain cover was installed and the silage stored in the silos adjacent to the Purebred Beef Unit barn for the predetermined test period.

The tower silo was filled by trucking the pressed waterhyacinth from Alachua sink and elevating it into the silo with chain-and-flight conveyors. A standard silage blower was found to be unsatisfactory because the wet material clogged the pipe. Citrus pulp and molasses were added to the waterhyacinth on the conveyor and the silage was continuously distributed and packed during filling. Thermocouples were installed at intervals and samples in cloth bags on ropes were burried for process monitoring.

Quantity of runoff from the barrel silos was measured and pH of the runoff was determined with a Heath pH meter. Temperatures of the silage in the culvert and tower silos were monitored twice a day until they fell to within a few degrees of ambient temperature. Observations were made by connecting a Thermo-Electric portable potentiometer to the previously buried thermocouples. Quantity

TABLE 1. WATERHYACINTH SILAGE TREATMENTS.

Additives	Standard cane molasses (%)			
	0.0	0.5	0.7	1.0
Grass + Dried citrus pulp (DCP)	X[a]	Z		
Chopped water hyacinth	X			
Pressed water hyacinth (PH)	A,B,B,X	A,B	Y	A,B
PH + 2.0% DCP	A,B,B,B, C,D,E	A,B,C,D, E,Z		A,B,C,D, E
PH + 3.4% DCP	Y			
PH + 4.0% DCP	A,B,X	A,B,C,D, E,Z,Z		A,B,C,D, E,Y
PH + 5.1% DCP				M
PH + 4.0% dried water hyacinth (DH)	A			A
PH + 2.0% cracked yellow dent corn (YDC)		E		
PH + 4.0% YDC		E		

[a] A—barrel silo, single light pressing, January, 61 days
B—Barrel silo, multiple heavy pressings, March, 63 days
C—barrel silo, multiple heavy pressings, June, 26 days
D—barrel silo, multiple heavy pressings, August, 25 days
E—barrel silo, multiple heavy pressings, August, 60 days
M—tower silo, November
X—culvert silo, August, 67 days
Y—culvert silo, November, 136 days
Z—culvert silo, August, 96 and 216 days

and pH of the runoff from the culvert and tower silos were determined during some of the tests.

Upon completion of the culvert silo storage, the depth of silage and quantity of spoilage were found. The silage was removed, either in small daily quantities or completely, followed by cold storage, weighed, sampled and fed.

Silage from the tower silo was removed in daily quantities and fed to sheep and beef cattle to determine acceptability and effects on animal performance.

RESULTS AND DISCUSSION

Some aspects of performance of the presses used in these tests have been described by Bagnall et al. (2, 3) and Baldwin, et al.[5] The Vincent press produced a waterhyacinth ensiling material of 12.6 ± 1.5 (95% confidence interval) percent dry matter with press performance apparently dependant on pressure, season, and source of plants. Performance of the 23 cm press is shown in Table 2; water expression increased significantly with increasing pressure and number of pressings, and product dry matter content increased significantly with number of pressings.

Much of the silage dry matter was from additives because the additives were so much dryer than the waterhyacinth. The contribution of additives to the silage dry matter for both barrel and culvert silos is shown in Table 3. The contribution was not uniform because of the variability in waterhyacinth moisture content.

The density range of pressed waterhyacinth silage, shown in Table 4, was similar to silage densities published by ASAE (1). Depth of silage, in the range investigated,

TABLE 2. PERFORMANCE OF 23 CM PRESS IN ENSILING TESTS.

Pressure (N/m^2)	Pressings	Water Expression (%)	Dry Matter Expression (%)	Product Dry Matter Content (%)
76×10^3	1	45 ± 6[a] a[b]	10 ± 4	9.1 ± 1.4 x
145×10^3	1	55 ± 7 b	17 ± 7	10.5 ± 1.9 x
145×10^3	2	71 ± 6 c	23 ± 9	14.4 ± 2.2 y

[a] 95% confidence interval on mean
[b] letters indicate significant difference ($\alpha = .05$) by Duncans Multiple Range Test

TABLE 3. CONTRIBUTIONS OF ADDITIVES TO SILAGE DRY MATTER.

Additives	% of Silage Dry Matter
0.5% standard cane molasses[a]	2.6 ± 0.3
1% standard cane molasses	4.9 ± 0.6
2% dry additive[b]	12.9 ± 1.4
4% dry additive	23.2 ± 2.3

[a] assumed 75% dry matter
[b] dried citrus pulp, dried water hyacinth, cracked yellow dent corn (assumed 90% dry matter)

TABLE 4. WATERHYACINTH SILAGE DENSITY.

Silage type	Depth (cm)	Density (g/cc)
Chopped, culvert, initial	228	0.90
Pressed, culvert, initial	102-234	4.58 ± .06[a]
Multiple-pressed, barrel, initial	44-72	0.77 ± .03
Multiple-pressed, barrel, final	41-70	0.77 ± .03
Single-pressed, barrel, final	33-56	0.67 ± .02

[a] 95% confidence interval on mean

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[5] Baldwin, J. A., J. F. Hentges, and L. O. Bagnall. 1973. Preservation and Cattle Acceptability of Water Hyacinth Silage. Talk presented at the 13th Annual Hyacinth Control Society meeting held in New Orleans, La., July 16-18.

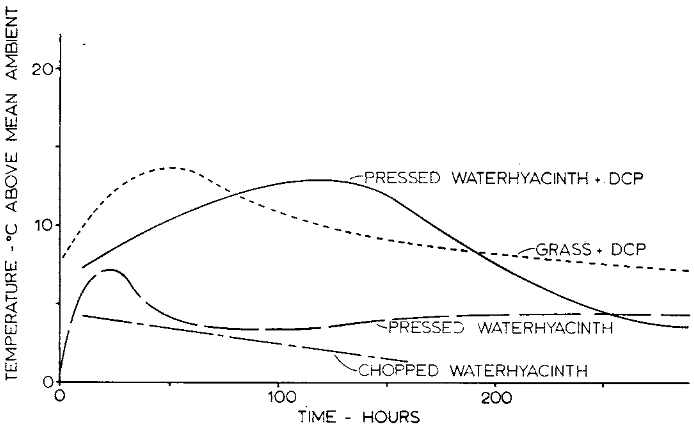

Figure 3. Effect of time on waterhyacinth silage temperature.

did not significantly affect density, but care in packing and degree of maceration did. The silage in the barrels did not change density during the storage period.

Good silage is usually produced by early high-level activity by lactic-acid producing bacteria, followed by a long period of relative inactivity, as indicated by heat production or pH change. The temperature histories of the culvert silage are shown in Figure 3. In most cases temperatures rose 3 to 6 degrees C. within 3 days after filling, then tapered off. In the cases of the better waterhyacinth silages, the temperature did not rise that much and in some cases showed no consistently detectable rise. In the first barrel silo test, runoff began early enough in the storage period and was of adequate quantity to establish a history. Typical histories for three classes of silage in the first test are shown in Figure 4. The rapid drop in pH at the beginning of the storage is typical of good silage fermentation. The subsequent rise is not usually considered satisfactory. The final average pH of 4.9 is higher than that usually found in good terrestrial forage silage. Most barrel silo tests did not yield enough runoff to establish curves, but what little was available indicated patterns similar to those shown. Final pH was related to minimum pH, as shown in Figure 5, according to the equation $pH_F = 2.22 + 0.643\ pH_{min}$ where pH_F=final pH and pH_{min}=minimum observed pH and is significant at $\alpha = .01$ with an r of .634. Final pH is related to additive level, as shown in Figure 6, by the regression equation $pH_F = 5.45 - 0.280$ DCP where pH_F=final pH, DCP=dried citrus pulp, % of pressed waterhyacinth and is significant at x=.01 with a correlation coefficient of 0.61. SCM made no significant contribution in a multiple regression analysis.

Silage shrinks during storage because of loss of water and solids, change in mechanical properties of fibers and settlement and shifting of particles. Shrinkages of waterhyacinth silage, as shown in Table 5, were extremely variable. The primary factor affecting shrinkage was packing during filling, as those silos poorly packed shrank much more. Secondary factors were initial moisture content and time, shrinkage increasing with both. The worst shrinkage was that of the chopped waterhyacinth, stored at 95% moisture content.

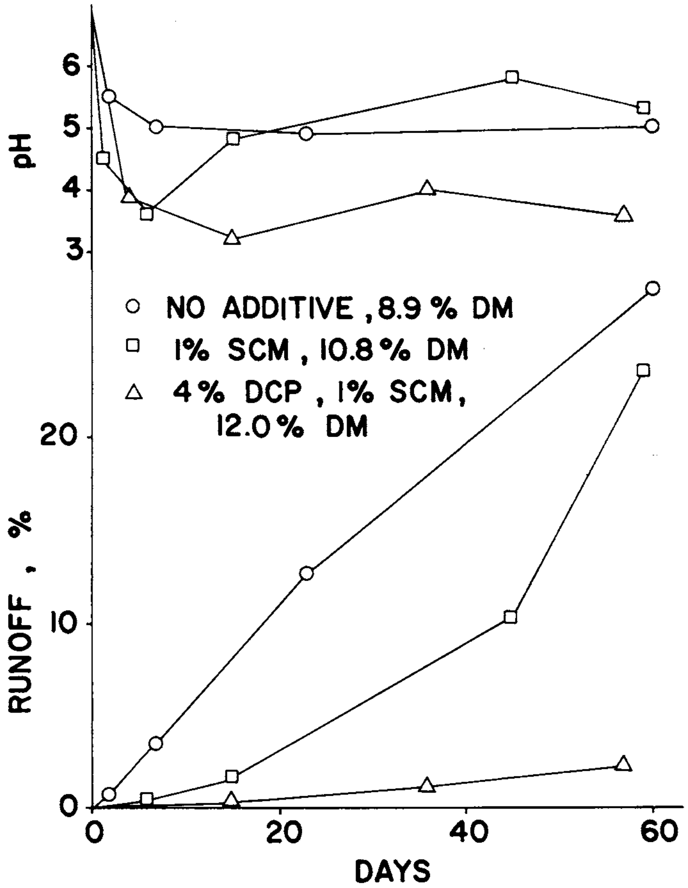

Figure 4. Effect of time on waterhyacinth silage pH and runoff.

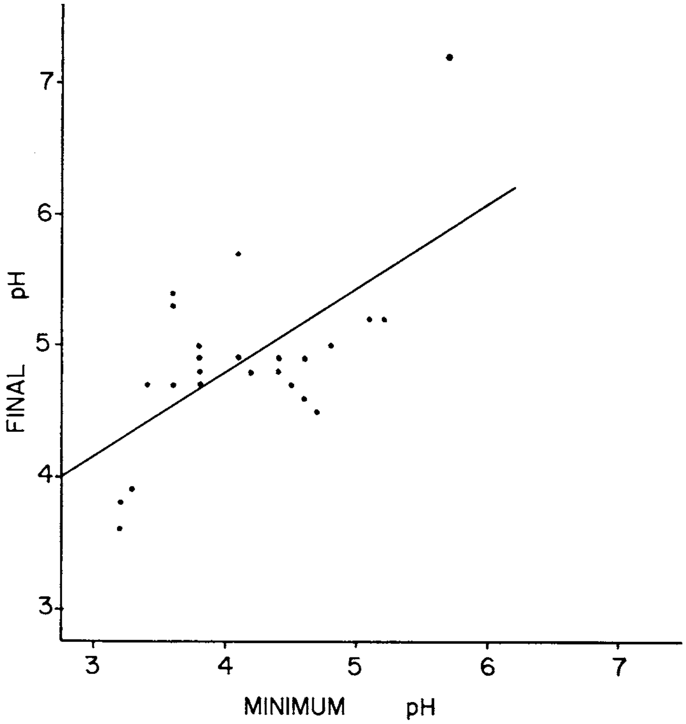

Figure 5. Final waterhyacinth silage pH vs. minimum observed pH.

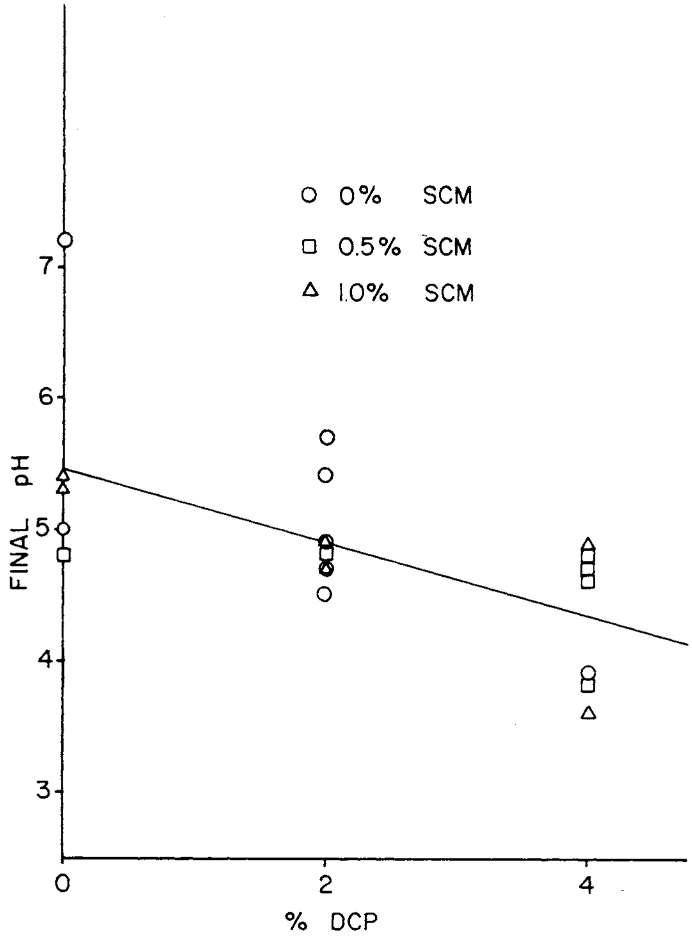

Figure 6. Effect of additive on waterhyacinth silage final pH.

In any silage system, there will be losses due to mold and spoilage, drainage, oxidation, and respiration. The losses from waterhyacinth silage in these tests are shown in Table 6. Spoilage and mold are pooled as visibly defective material removed and discarded after the silo was opened. The difference between initial and final weights of silage is classified as loss. Usable silage is the weight ratio of final unspoiled silage to initial components. The spoilage of the chopped waterhyacinth makes it unacceptable for silage. Spoilages of pressed waterhyacinth are acceptable when sizes of silos are considered. Spoilage in the barrel silos decreased with succeeding tests because of better packing, dryer material, and elimination of less satisfactory additive combinations. Grass silage spoilage was high because it was coarsely chopped, poorly packed, and not covered. Losses in the culvert silos were high, but can be partially attributed to poor estimation of initial weight. Loss from the barrel silos filled with multiple-pressed waterhyacinth are small, and that from all barrel silo tests is related to runoff by the regression equation $L=.424 + 1.23R$ – where L=loss, %, and R=runoff, %, significant at $\alpha=.01$, with a correlation coefficient of 0.95. Recovery of usable silage ranged from 32 to 98%, increasing with increasing dry matter content and dry carbohydrate additive level and decreasing with increasing storage time. Final dry matter content of the silage in the barrel silos was invariably lower than initial dry matter content, indicating oxidation and respiration of the dry matter, which coincides with the implication of the above regression.

TABLE 5. SHRINKAGE OF WATERHYACINTH SILAGE.

Silage type	Shrinkage (%)
Chopped, culvert	63
Pressed, culvert, 68 days	15
Pressed, culvert, 96 days[a]	40
Pressed, culvert, 217 days[a]	51
Grass, culvert, 59 days	7
Grass, culvert, 216 days[a]	57
Pressed, barrels, 25-68 days	2.7 ± 1.6[b]

[a] poorly packed
[b] 95% confidence interval on mean

TABLE 6. WATERHYACINTH SILAGE LOSSES.

Silage type	Spoilage (%)	Weight Loss (%)	Usable Silage (%
Chopped, culvert	100		0
Pressed, culvert, 68 days	6		
Pressed, culvert, 96 days[a]	8	19	73
Pressed, culvert, 217 days[a]	15	35	50
Grass, culvert, 216 days[a]	36	24	40
Single-pressed, barrel, January, 61 days	29 ± 4[b]	19 ± 9	52 ± 9
Multiple-pressed, barrel, March, 65 days	21 ± 3	5 ± 2	74 ± 4
Multiple-pressed, barrel, June-August, 25-60 days	12 ± 2	2 ± 3	86 ± 4

[a] poorly packed
[b] 95% confidence interval on mean

Runoff was nearly linear with time in those treatments which were wet enough to drain, as shown in Figure 4. Runoff decreased with increasing silage dry matter content, as shown in Figure 7 according to the regression equation $R=55.9 - 5.46\ DM + 0.129\ DM^2$ where R=runoff, % of initial silage weight, and DM=initial silage dry matter content, %, significant at $\alpha=.01$, with a correlation coefficient of 0.72.

Sheep and beef cattle rejected the chopped waterhyacinth silage and accepted pressed waterhyacinth silage

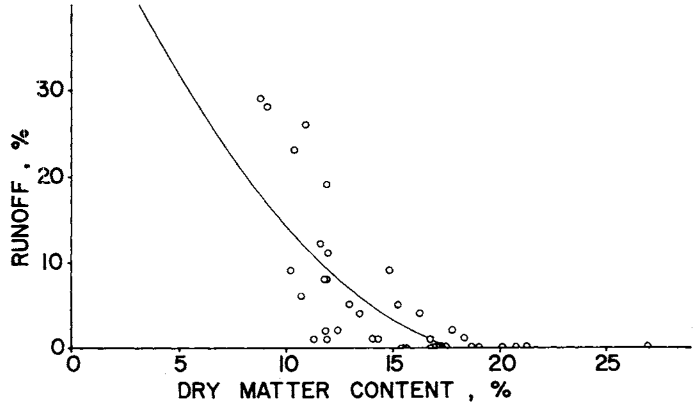

Figure 7. Effect of waterhyacinth silage dry matter content on runoff.

to varying degrees. Animal trials with most of these silages are reported by Baldwin, Hentges, and Bagnall.[5]

CONCLUSIONS

Acceptable silage can be produced from waterhyacinth by mechanically removing 50% or more of the water and adding free carbohydrates. Two to four percent dried citrus pulp or cracked yellow dent corn are satisfactory carbyhydrate sources and one percent or less standard cane molasses is not a satisfactory carbohydrate source. Pressed waterhyacinth silage with a moisture content below 85% does not drain in small silos.

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