Plant Nutritional Content Of Some Florida Waterhyacinths And Response By Pearl Millet To Incorporation Of Waterhyacinths In Three Soil Types[1]

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ABSTRACT

Waterhyacinths (*Eichhornia crassipes* (Mart.) Solms.) have a dry weight plant nutrient content similar to that of many agricultural crops. Complete removal of waterhyacinths from natural waters could substantially reduce concentrations of nutrients in the aquatic environment. The addition of harvested waterhyacinths to the soil with the subsequent release of nutrients to crops would enhance plant growth and help maintain soil organic matter. The average dry weight composition of waterhyacinths examined in this study was: 19.2% ash, 34.9% C, 1.61% N, 0.31% P, 3.81% K, 1.66% Ca, 0.56% Mg, 0.56% Na, 2568 ppm Al, 2772 ppm Fe, 286 ppm Mn, 58 ppm Zn, and 9 ppm Cu. The Cr content varied from 0 to 35 ppm and Pb was from 0 to 20 ppm. Water content of the fresh plant was 95% by weight. There was a positive response by pearl millet (*Pennisetum typhoides* (Burm.) Stapf and Hubb., cultivatar Pearlex 21) to waterhyacinth applications to sandy soils. This response was independent of mineral fertilizer applications and it was of greater magnitude in Leon Soil (pH 4.8) than in Arredondo soil (pH 6.5).

INTRODUCTION

Waterhyacinth is one of the most obnoxious aquatic weeds in the southeastern United States. Its rapid rate of growth reflects both favorable climatic conditions (13) and eutrophication of the aquatic habitat. Chemical and mechanical control methods have been used in an attempt to maintain streams, lakes, and canals free of waterhyacinth growth. In recent years, researchers (1, 3, 12, 19) have conducted studies into the utilization of waterhyacinth plant material as a source of nutrients for plant and animal growth. Knipling et al. (13) analyzed waterhyacinths which contained 1.75% N, 0.63% P, 3.07% K, 3.06% Ca, and 0.63% Mg on a dry weight basis. This nutrient content indicates that dried waterhyacinths would have utility as a soil amendment and nutrient source in crop production. This opens the possibility that the plant material from waterhyacinth growth would have an economical value in animal and plant nutrition. In addition, waterhyacinths were shown to be an effective agent in removing nutrients from eutrophic waters (15, 18).

Nutrient content of waterhyacinths varies with location, season of the year, and water quality. The amounts of available plant nutrients and the rate of nutrient release are important factors to consider in the use of waterhyacinths as a soil amendment. The objectives of this study were to characterize the chemical composition and nutrient availability of waterhyacinths and to evaluate nutrient release after incorporation of harvested plants into the soil.

METHODS AND MATERIALS

In order to gain some insight into the chemical variability of Florida's waterhyacinths, whole plants were sampled in representative lakes, streams, canals, and springs, on four separate occasions between June and December, 1972. Plant material was put into plastic bags which were sealed and placed on ice for transport to the laboratory. The plants were dried at 70 C and ground

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in a Wiley mill to pass a 20-μ screen for chemical analyses. Carbon was determined in a carbon-hydrogen analyzer with a combustion time of 233 sec and a temperature of 900 C (7). Nitrogen content was determined by the salicylic acid modification of the Kjeldahl method (4). For ash determination, 2 g of plant material were ignited at 500 C for 8 hr, cooled, and weighed. The ash was dissolved in 0.1 N HCl for other elemental determinations. Phosphorus content was determined colorimetrically by the molybdate method with stannous chloride or ascorbic acid as the reducing agent (11, 16). Potassium and Na content were determined by flame emission and other metals by atomic absorption spectrophotometry (9). In addition to total elemental content, water soluble nutrients were determined in saturation extracts of dried plant material after filtration through a 0.22-μ filter. Chlorides were determined with a specific ion electrode.

A greenhouse experiment was designed to study the release of plant nutrients by waterhyacinths when mixed with samples from the plow layer (0 to 15 cm) of three uncultivated Florida soils: Arredondo sand (Grossarenic Paleudalf), Lakeland sand (Typic Quartzipsamment), and Leon fine sand (Aeric Haplaquod). The soils were dried, sieved through a 2-mm screen, and weighed into 5-kg portions for subsequent mixing with appropriate fertilizer or waterhyacinth additions. The experimental design was a factorial with three levels of N-P-K (0-0-0,45-25-50, and 90-50-100 ppm) and four levels of dried waterhyacinths (0, 2231, 4462, and 8924 ppm) in completely randomized blocks of three replications. Reagent grade NH_4NO_3, KH_2PO_4, and KCl were used as mineral sources of plant nutrients. Waterhyacinths harvested in August 1972 from Lake Alice on the University of Florida campus dried and ground to pass through a 2-mm screen, supplied the organic source on the University of Florida campus, dried and ground to mixed thoroughly with the 5-kg of soil for each treatment which was then placed in a black polyvinyl pot. Each pot was seeded to pearl millet and later thinned to ten seedlings per pot. The plants were harvested 6 weeks later. After the first crop was removed, pearl millet was again planted with no additional application of fertilizer or waterhyacinths and the same number of plants were harvested (second crop) at the same age as before. The greenhouse temperature was maintained at about 25 C and the pots were irrigated weekly with sufficient distilled water to increase the soil water content to 20% by volume. Plant tissue was dried at 70 C, weighed, and ground to pass a 20-μ screen for chemical analyses.

RESULTS AND DISCUSSION

The contents of plant macronutrients in waterhyacinths collected from central Florida are presented in Table 1. The relatively high ash content of waterhyacinths from the first four locations listed was probably caused by the roots being in contact with bottom sediment as the water was quite shallow (< 15 cm). Carbon content varied from 18 to 40% with an overall average of about 35%, which is comparable to values normally found among terrestial plants. Total N varied from a low of 0.86% to a high of 2.86% and these values are also comparable to those reported by other investigators (1, 13, 19, 20).

The most important factor for one to consider when adding an organic residue to the soil is the C:N ratio which averaged about 23:1 in the waterhyacinths sampled. This value is within the range of C:N ratios of 20:1 to 30:1 found in legumes and much lower than the 90:1 ratio of most straws (6). The addition of organic matter (OM) to a normal soil evokes an immediate response from the soil microbes which eventually degrade the OM into its basic components and leave a more or less stable residue, soil humus. During this biological process the C:N ratio tends to equilibrate at the same level as present in the soil itself which averages about 11:1 in normal mineral soils. The microbes require N for their metabolism with the concomitant evolution of CO_2. This N is obtained from

TABLE 1. PERCENT CHEMICAL COMPOSITION BASED ON DRY WEIGHT OF WATERHYACINTHS COLLECTED FROM VARIOUS BODIES OF WATER IN FLORIDA.

Origin	Ash	C	N	C/N ratio	P	K	Ca	Mg	Na
Lake Istokpoga (Sebring)	24.4	18.0	1.08	16.7	0.14	1.00	0.73	0.38	0.15
Lake Eden Canal (SR 532)	19.4	28.8	0.86	33.5	0.09	1.95	0.46	0.31	0.23
Lake Thonotosassa	23.0	23.0	1.17	19.7	0.33	3.35	1.49	0.29	0.21
Waverly Creek (SR 60)	25.0	33.1	2.26	14.6	0.56	3.10	1.58	0.50	0.37
Arbuckle Creek	23.4	34.9	1.90	18.4	0.23	3.35	1.06	0.49	0.28
Lake Tohopekaliga (Kissimmee)	21.7	34.0	1.69	20.1	0.60	4.70	1.56	0.71	0.53
Lake Monroe (Sanford)	20.4	32.5	2.86	11.4	0.59	5.55	1.73	0.54	0.83
Duda Canal No. 1 (Belle Glade)	20.3	39.1	1.30	30.1	0.13	3.80	1.99	0.60	0.48
St. Johns River (Astor)	20.1	36.4	2.33	15.6	0.51	6.50	1.43	0.51	0.63
W. R. Grace Landfill (Bartow)	19.0	36.4	1.86	19.6	0.59	2.72	1.99	0.56	1.54
Ponce de Leon Springs	18.5	37.5	1.74	21.5	0.33	5.40	2.34	0.50	0.47
Waverly Creek (SR 540)	18.5	38.1	1.76	21.6	0.32	4.85	1.45	0.55	0.67
Duda Canal No. 2 (Belle Glade)	17.5	37.8	1.66	22.8	0.15	4.70	2.28	0.69	0.57
Lake Alive (N. of Fla)	17.3	38.6	1.17	33.0	0.40	3.66	2.41	0.69	0.40
Lake Apopka (Montieverde I)	15.8	38.8	1.22	31.8	0.14	4.26	2.07	0.54	0.41
St. Johns River (Palatka)	15.8	38.0	1.82	20.9	0.16	3.44	1.83	0.73	0.86
Lake George	15.4	40.2	1.48	27.1	0.21	3.21	1.91	1.86	1.24
Lake Apopka (Monteverde II)	14.9	39.8	1.36	29.3	0.09	4.08	1.96	0.60	0.21
Lake East Tohopekaliga (St. Cloud)	14.7	37.2	1.08	34.5	0.23	2.90	1.19	0.51	0.53
MEAN	19.2	34.9	1.61	23.3	0.31	3.81	1.66	0.56	0.56
Standard deviation	3.2	5.9	0.50	7.0	0.18	1.30	0.53	0.14	0.36

TABLE 2. ALUMINUM AND SOME HEAVY METAL CONCENTRATION (PPM) BASED ON DRY WEIGHT OF WATERHYACINTHS COLLECTED FROM BODIES OF WATER IN FLORIDA.

Origin	Al	Cr	Cu	Fe	Pb	Mn	Zn
Lake Istokpoga (Sebring)	6050	35	3	8125	20	408	53
Lake Eden Canal (SR 532)	1850	8	8	3250	ND[a]	295	39
Lake Thonotosassa	1950	5	5	775	10	203	27
Waverly Creek (SR 60)	6750	8	13	5625	ND	238	81
Arbuckle Creek	3250	5	3	2000	ND	225	48
Lake Tohopekaliga (Kissimmee)	6350	10	8	5125	10	560	61
Lake Monroe (Sanford)	2250	5	40	2125	ND	310	192
Duda Canal No. 1 (Belle Glade)	150	ND	5	375	10	115	15
St. Johns River (Astor)	2900	ND	8	525	ND	170	100
W. R. Grace Landfill (Bartow)	9290	10	5	1940	ND	279	18
Ponce de Leon Springs	50	3	3	800	10	615	32
Waverly Creek (SR 40)	3000	3	8	3125	ND	193	45
Duda Canal No. 2 (Belle Glade)	250	ND	8	500	ND	68	26
Lake Alice (U. of Fla.)	853	ND	10	657	10	402	69
Lake Apopka (Monteverde I)	298	ND	5	160	10	122	22
St. Johns River (Palatka)	1181	ND	10	1150	10	464	69
Lake George	904	ND	10	755	10	287	51
Lake Apopka (Monteverde II)	425	ND	5	135	20	219	39
Lake East Tohopekaliga (St. Cloud)	1050	3	8	15500	10	253	107
MEAN	2568	—	9	2772	—	286	58
Standard deviation	2668	—	8	3765	—	147	42

[a]None detected.

the added OM where the C:N ratio is small (< 30:1) or from the soil where the C:N ratio is large, in which case there is a temporary depletion of available N with detrimental effects on higher plants.

The contents of other macronutrients shown in Table 1, (i.e. P, K, Ca, and Mg) were comparable to like values for most feed and forage plants (8, 10, 13). The elemental content of OM is an important aspect to consider before its use as a soil amendment or plant nutrient source. The presence of undesirable elements, toxic to plants or animals, may deter the use of organic materials in feed or feed production. The Na content should present no problem as most crops respond favorably to Na applications (14).

Aluminum content (Table 2) was relatively high in all but a few samples of waterhyacinths, and this could pose a hazard if large amounts of waterhyacinths were applied to soil in which Al-sensitive plants are growing. Chromium was found in only a few waterhyacinth samples and, as it is not an essential plant nutrient, its presence or absence in OM applied to soil should not present a problem. On the other hand, Cr is commonly found in soils derived from serpentine in the range of 10 to 1,000 ppm (17) and in amounts measurable as ppb in natural waters where it is considered as an industrial pollution indicator when present in higher concentration (21). The Fe content was relatively high, which should be an asset in using water-

TABLE 3. IONS EXTRACTED WITH WATER FROM GROUND (20u) OVEN DRIED (70 C) WATERHYACINTHS COLLECTED FROM VARIOUS BODIES OF WATER IN FLORIDA.

Origin	Cl	K	Na	Ca	Mg	P	Al	Cr	Fe	Mn	Zn
			(%)					(ppm)			
Lake Istakpoga (Sebring)	0.61	0.94	0.11	0.08	0.15	138	61	1	46	47	5
Lake Eden Canal (SR 432)	3.03	1.27	0.14	0.10	0.12	114	446	1	11	52	8
Lake Thonotosassa	2.09	0.31	0.19	0.14	0.20	2580	6	2	8	32	5
Waverly Creek (SR 60)	1.93	2.59	0.31	0.14	0.23	2360	30	4	62	27	11
Arbuckel Creek	2.04	2.75	0.19	0.07	0.52	808	61	1	48	53	16
Lake Tohopekaliga, (Kissimmee)	2.75	3.52	0.37	0.10	0.38	1408	ND[a]	2	36	99	22
Lake Monroe (Sanford)	4.95	4.07	0.65	0.20	0.33	3724	ND	14	28	44	54
Duda Canal No. 1 (Belle Glade)	2.92	3.41	0.40	0.21	0.40	572	ND	2	6	35	8
St. Johns River (Astor)	3.91	4.24	0.48	0.10	0.37	3129	ND	2	11	27	31
W. R. Grace Landfill (Bartow)	2.70	2.26	1.29	0.25	0.45	3190	6	ND	48	79	3
Ponce de Leon Springs	3.03	3.74	0.36	0.18	0.27	1760	ND	1	13	109	7
Waverly Creek (SR540)	2.97	3.58	0.52	0.08	0.38	1705	ND	3	56	44	11
Duda Canal No. 2 (Belle Glade)	6.11	6.49	0.75	0.30	0.73	990	ND	5	14	25	18
Lake Alice (U. of Fla.)	4.68	5.50	0.54	0.29	0.70	2596	ND	3	12	54	10
Lake Apopka (Monteverde 1)	2.59	3.74	0.32	0.20	0.35	869	ND	1	5	32	4
St. Johns River (Palatka)	2.70	2.75	0.61	0.13	0.46	808	22	2	28	147	16
Lake George	3.08	2.64	0.94	0.11	0.56	929	22	2	24	96	15
Lake Apopka (Monteverde II)	2.20	3.19	0.13	0.11	0.34	1105	40	1	5	59	13
Lake East Tohopekaliga (St. Cloud)	1.43	2.26	0.43	0.04	0.29	512	121	2	47	449	22
MEAN	2.93	3.12	0.46	0.15	0.38	1542	—	—	35	58	15
Standard Deviation	1.27	1.47	0.30	0.08	0.16	1089	—	—	38	33	12

[a]None detected

TABLE 4. SOME CHEMICAL CHARACTERISTICS OF VIRGIN FLORIDA SOILS AND LAKE ALICE WATERHYACINTHS USED IN THE GREENHOUSE STUDY.

Soil Type	pH water	C (ppm)	N (ppm)	C:N ratio	NO_3	P	K	Ca	Mg
					ppm[a]				
Arredondo	6.5	7470	665	11	90	2	75	13	2
Lakeland	5.0	5120	234	22	25	2	3	8	1
Leon	4.8	15070	593	25	34	3	10	10	1
Waterhyacinths	7.5	340000	11000	31	3	1530	36500	1700	3875

[a]Determination performed on a saturation extract.

hyacinths for soil applications. The Zn and Mn contents also add to their potential value. The small amount of Pb in waterhyacinths poses no threat as to subsequent uptake in edible plant tissue (5). Most of the K and Na in waterhyacinth plants was water soluble (Table 3). Other elements that were measured, with the exception of P, appeared to be highly water insoluble. This seemed to be especially true of Al and Fe.

Selected chemical properties of the Arredondo, Lakeland, and Leon soils and the waterhyacinths used in the greenhouse study are shown in Table 4. The Arredondo soil more closely approached ideal conditions for plant growth with regard to soil pH and C:N ratio than did the other two soils. The relatively high pH of the waterhyacinths would certainly be a beneficial characteristic where large quantities of waterhyacinths are disposed of on sandy, acidic soils. Waterhyacinth additions alone to Arredondo sand did not increase millet yields in the first crop; however, when applied in addition to fertilizer, there was a positive response to waterhyacinths over and above the response to fertilizer alone (Table 5). Uptake of N-P-K by millet plants followed almost the same pattern as yields. An interaction occurred between N and K uptake which was not exhibited in P uptake. The second millet crop yields were much less than the first crop yields and the residual effect of fertilizer alone was not significant. However, there was a residual effect from waterhyacinth applications with or without added fertilizer. Waterhyacinth applications seemed to enhance nutrient uptake through a possible improvement of the root environment in addition to maintaining a source of plant nutrients.

The Lakeland sand was inherently less fertile than the Arredondo sand. This was manifested in greater yield response by pearl millet to fertilizer applications and there

TABLE 5. YIELD AND MAJOR NUTRIENT UPTAKE BY TWO PEARL MILLET CROPS ON ARREDONDO SAND.

Treatment: Fertilizer N-P-K	Treatment: Waterhyacinths ppm	Yield g/pot	Nitrogen	Phosphorus	Potassium
				mg/pot[a]	
				First Crop	
0-0-0	0	3.7ab[b]	58a	12.6a	201ab
0-0-0	2231	2.9a	51a	16.2abc	174a
0-0-0	4462	2.7a	52a	14.9ab	166a
0-0-0	8924	4.0ab	72a	22.4cde	248abc
45-25-50	0	5.4bc	161b	17.6abcd	313bc
45-25-50	2231	8.5def	226cd	23.9def	536ef
45-25-50	4462	7.1cde	214cd	21.9bcde	470de
45-25-50	8924	8.9ef	257de	27.1ef	588ef
90-50-100	0	6.6cd	202bc	23.2cde	366cd
90-50-100	2231	8.5def	302ef	26.8ef	600ef
90-50-100	4462	9.4f	329f	30.5f	640f
90-50-100	8924	8.6def	296ef	31.1f	606ef
				Second Crop	
0-0-0	0	0.7a	28a	1.9a	17a
0-0-0	2231	2.0abcd	43a	5.0ab	71abcd
0-0-0	4462	3.3bcde	69ab	7.6b	126bcde
0-0-0	8924	3.4cde	79abc	8.9b	138cde
45-25-50	0	1.7abc	62a	5.7ab	57abc
45-25-50	2231	2.8bcde	65a	6.2ab	108bcde
45-25-50	4462	2.3abcde	81abc	5.2ab	101bcde
45-25-50	8924	3.5cde	75ab	8.2b	141de
90-50-100	0	1.3ab	50a	4.8ab	45ab
90-50-100	2231	3.5cde	130bcd	8.9b	154de
90-50-100	4462	4.2e	138cd	9.2b	175e
90-50-100	8924	3.9de	150d	9.6b	173e

[a]To convert mg/pot to ppm divide by 5.

[b]Means in a column for each crop followed by the same letter are not significantly different at the 5% level as determined by the New Duncan's Multiple Range test.

TABLE 6. YIELD AND MAJOR NUTRIENT UPTAKE BY TWO PEARL MILLET CROPS ON LAKELAND SAND.

Treatment: Fertilizer N-P-K	Treatment: Waterhyacinths ppm	Yield g/pot	Nitrogen (mg/pot[a])	Phosphorus (mg/pot[a])	Potassium (mg/pot[a])
				First Crop	
0-0-0	0	1.0a[b]	23a	2.9a	17a
0-0-0	2231	2.5a	34a	5.7a	123ab
0-0-0	4462	2.5a	37a	7.7a	136ab
0-0-0	8924	2.1a	48a	6.6a	111ab
45-25-50	0	4.4b	160b	15.7b	161b
45-25-50	2231	6.9cd	200bc	22.2bc	426d
45-25-50	4462	8.1d	199bc	24.3bc	504d
45-25-50	8924	7.2cd	178b	23.2bcd	451d
90-50-100	0	5.2bc	233cd	26.7cd	300c
90-50-100	2231	8.0d	273d	30.9d	502d
90-50-100	4462	7.6d	259d	30.0cd	540d
90-50-100	8924	6.5cd	202bc	22.7bc	463d
				Second Crop	
0-0-0	0	0.6a	17a	0.6a	9a
0-0-0	2231	1.5ab	21ab	2.5ab	51ab
0-0-0	4462	1.6ab	34ab	4.5abc	50ab
0-0-0	8924	1.4ab	43abc	2.6ab	63ab
45-25-50	0	3.0ab	59abc	6.8abc	73ab
45-25-50	2231	3.5bc	104cde	6.2abc	108ab
45-25-50	4462	3.7bc	64abc	7.1abcd	130bc
45-25-50	8924	2.9ab	81bcd	6.2abc	129bc
90-50-100	0	4.2bc	130de	10.3cd	99ab
90-50-100	2231	7.4d	156e	17.53	218cd
90-50-100	4452	4.1bc	140de	9.5bcd	143bc
90-50-100	8924	5.9cd	161e	14.0de	242d

[a]From mg/pot to ppm multiply by 1/5.
[b]Means in a column for each crop followed by the same letter are not significantly different at the 5% level as determined by the New Duncan's Multiple Range test.

TABLE 7. YIELD AND MAJOR NUTRIENT UPTAKE BY TWO PEARL MILLET CROPS ON LEON SAND.

Treatment: Fertilizer (N-P-K)	Treatment: Waterhyacinths (ppm)	Yield g/pot	Nitrogen (mg/pot[a])	Phosphorus (mg/pot[a])	Potassium (mg/pot[a])
0-0-0	0	0.3a	12a[b]	0.4a	6a
0-0-0	2231	3.0b	78b	10.3ab	168bc
0-0-0	4462	5.1bc	120bc	18.9bcd	277cdef
0-0-0	8924	4.5bc	125bc	23.9bcde	304derg
45-25-50	0	3.2bc	139bcd	16.7abc	138b
45-25-50	2231	3.5bc	123bc	17.7abc	203bcde
45-25-50	4462	5.2bc	158cd	32.0cde	317defg
45-25-50	8924	5.4bc	164cd	36.6de	343fg
90-50-100	0	3.4bc	138bcd	18.4abcd	187bcd
90-50-100	2231	5.2bc	192cd	30.0cde	312defg
90-50-100	4452	5.3bc	204d	35.3cde	329efg
90-50-100	8924	6.4c	211d	41.4e	415g
0-0-0	0	0.2a	10a	0.4a	2a
0-0-0	2231	2.2abc	53bc	4.3a	71bc
0-0-0	4462	3.1cd	68bcd	8.7ab	101cd
0-0-0	8924	2.9c	84cd	13.7abc	117cd
45-25-50	0	1.0ab	38b	6.7ab	27ab
45-25-50	2731	2.0abc	69bcd	11.1ab	83bcd
45-25-50	4462	3.5cde	125e	16.5bc	148de
45-25-50	8924	4.6def	147e	19.6bcdc	186ef
90-50-100	0	2.1abc	91d	19.5bcd	79bcd
90-50-100	2231	4.9ef	182f	33.8e	207ef
90-50-100	4452	5.0ef	182f	30.5de	231f
90-50-100	8924	5.7f	200f	27.5cde	242f

[a]From mg/pot to ppm multiply by 1/5.
[b]Means in a column for each crop followed by the same letter are not significantly different at the 5% level as determined by the New Duncan's Multiple Range test.

were further increases from fertilizer-waterhyacinth combinations. The residual effect from fertilizer and waterhyacinth applications was much more pronounced in Lakeland sand than in Arredondo sand—the second millet crop averaged 63% of the first crop in Lakeland sand and 42% in the Arredondo sand.

Plants grown on Leon sand exhibited the greatest response to fertilizer and waterhyacinth applications of the three soils studied. Waterhyacinth applications alone produced either as good as or better yields than fertilizer applications alone (Table 7). Also, the residual effects of fertilizer and waterhyacinth were quite evident as manifested by second crop yields which were 74% of the first crop yields. In addition to increasing yield, waterhyacinth applications increased N-P-K uptake by both crops of millet. The high base content of the hyacinths was probably effective in reducing Al toxicity associated with unlimed Leon soils (2).

Millet grown on Leon sand showed a positive response to waterhyacinth additions independent of fertilizer treatment. The first crop grown on Arredondo sand showed a slight yield depression on treatments of 2231 ppm and 4462 ppm of waterhyacinths and no fertilizer. In the second crop, decomposition of waterhyacinths supplied plant nutrients, and yields above the controls were obtained. Optimum response to applied waterhyacinths by millet grown on Lakeland was at the lowest rate of application, with steady declines thereafter.

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