Giant *Leucaena* "Wood Grass" – A Bioenergy Crop for the Lower South, USA

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ABSTRACT

Giant *Leucaena*, a perennial forage and tree legume from the Americas, has been studied in Florida since 1979 beginning at the UF Agronomy Research Station in Gainesville, FL. High yielding accessions were selected for vigor and persistence from that world collection and planted in central FL by the junior author. The concept "wood grass" involves planting high populations to attain tall, woody stems to 20 ft with a heavy canopy until frost. In mid-summer on a sandy soil, an established 7 year-old stand of K636 at St. Leo, FL, produced 75.3 Mg/ha fresh weight, and 28.5 Mg/ha dry weight. Fermented as green chop, methane gas (CH_4) containing 224 x 10^6 Btu and 37 metric tons of dry compost containing 874 kg of N are produced per hectare. Three-year-old giant-type *Leucaena* from Brazil planted no-till as "wood grass" on reclaimed mined land in Polk County, FL, produced 77.9 Mg/ha fresh weight and 29.6 Mg/ha dry weight after one full season. Full season "wood grass" will yield 455 x 10^6 Btu/ha, 40% of which is useful energy in Integrated Gasifier Combined Cycle (IGCC) systems. Anaerobic fermentation and IGCC systems using giant *Leucaena* grown in central Florida should be carefully considered for renewable energy.

INTRODUCTION AND LITERATURE REVIEW

The post-Colombian historical record indicates that the genus Leucaena was first introduced into the Florida peninsula during the time of the galleon trade which was from the 16^{th} to the 19^{th} centuries. Seed of the "common" types was used for both human food and animal fodder on vessels traveling from Mexico to the Philippines (3). For Mayan Americans, the plant was more than food; it was part of their rich culture since at least the year 1500. The present-day Mexican State of Oaxaca is one of Leucaena's centers of origin for the name "Oaxaca" is a mis-transcription of the Zapotec word "Uaxin" which means "the place where Leucaena grows" (15). Generally, the center of origin of the genus, of the family Mimosaceae, is Central America and the Yucatan peninsula (3). It may also be a North American genus: a very robust natural hybrid (8 inch diameter in Gainesville, FL, USA)) was collected in Waco, Texas, USA, in this century (23). It seems clear, however, that the more abundant "common" types, all of the species *L. leucocephala* (Lam.) de Wit, were left wherever early traders traveled. This included South Florida. Other species in the genus, including the red Leucaenas, have occupied a less extensive range. The following literature review should be helpful for those who know Leucaena only as a perennial legume browse crop. Following Leucaena's brief history in Florida, we wish to present useful data from the harvest of established giant Leucaenas grown as an energy crop on sand and clay.

The second time significant quantities of Leucaena seed were brought to peninsular Florida was in the 20^{th} century. In 1979, G. Mott and B. Occumpaugh, of the UF Agronomy Dept., in an effort to identify promising forage legume species for the state, requested germplasm from the United States Department of Agriculture. A. Oakes, at that time a principle explorer of the species in the Americas, provided most of the 373 accessions, or PIs, which had been collected principally in central America and Mexico. A vast majority of the accessions are arboreal or "giant" types which grow up to 20 meters and are sparsely branched with better wood production than the shorter varieties; hence the name "giant Leucaena" (3). These were planted by I. Valencia, an Agronomy graduate student, as part of her Masters Thesis (23). The Gainesville, FL, World Collection, as it came to be known, was established from seed representing ten of the eighteen then known species of Leucaena. All of the accessions had been assigned a six-figure PI or plant introduction number. Some accessions had already been assigned a shorter number accompanied by the letter "K" – for example K636. The "K", used with a one to three-digit number, stands for the first letter of the Hawaiian word for Leucaena – "Koa haole."

The Gainesville World Collection (GWC), since 1979, has suffered numerous hard freezes (averaging one every four years) and invasions by countless weed species. By 2002, a majority of the 373 accessions have either totally disappeared or have lost vigor and persistence. In the 80's, however, the one-acre stand was maintained and studied by UF's G. Prine and a small group of dedicated graduate students and field workers. M. Othman conducted yield and forage evaluation work on selected accessions from 1984-87 (16). The "Othman 12" became twelve top accessions found to be both vigorous and persistent and which served in the next decade as the basis for further study by the authors. The average oven-dry stem yield during four growing seasons (1982, 1983, 1886 and 1987) of the "Othman 12" was 31.4 Mg/ha (14.0 t/a). The bioenergy potential of this yield was studied by A. Green in a uniquely designed "Co-combustion in Community Waste-to-Energy" pilot. Translated to conventional usage, 14.0 dry tons per acre represent as much as 218.4 million Btu per acre (9).

At the University of Hawaii, the genus was being considered. J. Brewbaker worked on a now well-known National Academy of Science Press monograph published twice in 1977 and 1984 (15). In fact, worldwide, the interest in Leucaena was at a high point due mainly to its having been in both small holding and commercial agriculture for decades. A yearly Leucaena Research Reports, containing summary research articles from experiences around the world, was published for twelve years (21). By the mid 1980's *Leucaena leucocephala* had become considered one of the most economically versatile of plant species; fuel wood, fodder, fertilizer, human food and soil building properties made it a much hoped-for "miracle" tree. The scenario became un-rosy in 1985, however. Before the Hawaiians were able to complete a biomass-to-electricity project (2), the attack of the psyllid was launched.

The worldwide outbreak of the jumping plant louse, (*Heteropsylla cubana* Crawford) originated in the Caribbean basin in 1982 or 1983. The sap-sucking psyllid, a Homopteran species, found climactic conditions nearly perfect for migration on equatorial wind currents around the tropics and descent on Leucaena fields. Hundreds of thousands of hectares in Indonesia, Philippines, Southeast Asia, Africa and Australia had been attacked by 1986 (14). Though few established stands were killed, no Leucaena-growing country or island was spared. The GWC at Lake Alice was hit in the middle of the 1983 growing season limiting Othman's forage evaluations (17). Having been brought "down to earth" by reality, Leucaena scientists began to identify tolerant and possibly resistant accessions (8). The USDA in Brooksville, FL, participated in the screening of genotypes. M. Williams and UF graduate student M. Austin found psyllid tolerance in K636 and K467 among others (1). Possibly due to yearly frosts in the state, no serious outbreak of the psyllid has affected nurseries of Leucaena in Florida since 1984.

Beginning in1989, selected Leucaena germplasm from the GWC was brought to a 4-acre nursery at Saint Leo Abbey by three UF-educated agronomists of the newly established Center of Sustainable Agroforestry, Inc. (Cosaf). Seed from the GWC had been collected in 1993 from most of the vigorous and persistent accessions. Three GWC accessions, two *L. diversifolia*s, and a *L. lanceolata,* were uprooted and moved to the new nursery. The largest growing accession in the GWC (8" dbh in 4 years) was originally from seed found in Waco, Texas (23); it is growing at both Cosaf nurseries in central FL. In 1991 Cosaf agronomists began working with G. Prine, the New Crops Agronomist in the Agronomy Dept., who had guided several graduate students in mainly forage studies. Based on the desire to locate and characterize the "Othman 12" nearly 10 years after the latter's work, two new studies focusing on biomass were conducted (4) (5). Six of the "Othman 12" accessions were found to have survived with high vigor and persistence. Adjusted average yields over four growing seasons (1990-1993) from 10 accessions showed much lower but still respectable dry matter yields of 19.2 Mg/ha (8.6 t/a). It was concluded that other than a possible overly rigorous (plot) adjustment technique, the hard freeze of 1989 was most responsible for the decline in average yields from 1985 to 1995.

At the same time the selection work in the GWC was being done, essential steps forward were taken by the Florida Institute of Phosphate Research (FIPR) and Polk County Extension to study the potential productivity of reclaimed phosphate mined areas known as clay settling ponds. For nearly 10 years Polk County Extension Agents J. Stricker and D. Shibles along with UF/IFAS researchers and support personnel from several departments measured the productivity of these soils. Although the results indicated that most crops grow very well on these colloidal clays, the long-lived perennials - giant Leucaena, the tall grasses and Eucalyptus - are among the best (22). Agronomists P. Mislevy and M. Adjei included one giant Leucaena accession in their work on clay and recorded a 58.5 Mg/ha (26 t/a) dry weight yield after only one year's growth (13). Also on clay at Green Bay, D. Shibles planted one-acre of McCarty giant (possibly K8) in 1993. After four growing seasons the widely spaced trees had accumulated 122 Mg/ha (50 t/a) dry weight in stems alone (6). (See Fig. 3 below.)

Cosaf's agronomists proposed growing Leucaena as "wood grass" on clay ponds in order to apply agronomic instead of forestry principles and thus reduce harvesting costs. "Wood grass" is a new concept in the agronomic literature. Widely spaced trees had been the norm. But, in a review of the literature in 1993, the authors found a 1953 study from the Hawaiian Agricultural Experiment Station that suggested Leucaena could be grown somewhat like alfalfa (12). Narrow rows and high plant populations were used by D. M. Kinch and J. C. Ripperton for leaf meal production. Ironically, the seed used was from the common, seedy types spread over the islands centuries before. No thought was given to allowing such a planting to grow taller than two or three feet. Would Leucaena become a tree under such conditions if planted in Florida? As the half-life of Leucaena is thought to be over fifty years (20), the hypothesis was formulated that Leucaena "wood grass", in one full growing season, would become more like the tall grasses and less like a tree and could be harvested with conventional machinery.

Finally, with clay ponds in mind, Cosaf agronomists sought a sponsor for a commercial planting of giant Leucaena. The clay ponds available in Polk County, FL, however, had become infested with a noxious weed - cogon grass. Cogon grass, *Imperata cylindrica,* (L) Raeuschel, had been carelessly introduced as a potential pasture species. Ranked the seventh worst weed in the world, it has escaped onto thousands of acres in Florida, Alabama, Mississippi and Louisiana (7). It forms a thick rhizome mat that produces tall, stem-less, serrated and unpalatable leaves. Given these novelties, no one was willing to predict success much less sponsor a commercial planting of giant Leucaena except D. Glick of the Corporation for Future Resources (CFR). A risky no-till approach was decided upon since reducing cost was a major factor. The CFR objective was to have enough feedstock with which to experiment on a pilot scale; harvesting and bio-conversion studies were to follow.

Commercial quantities of giant Leucaena seed were identified by Cosaf in the early 1990's. P. Raymond of Matto Grosso, Brasil, came to Florida then in search of rumen inoculum for cattle browsing Leucaena (11). He had increased seed of varieties developed by M. Hutton, of Australia, while the latter was in Brasil (19). "Hybrid", "Forte" and "Texas" were new Hutton lines and were used for the present study.

MATERIALS AND METHODS

By 1998 seed of the best accessions from the GWC had been collected by Cosaf agronomists and planted both at St. Leo Abbey and in a new nursery in central Florida on former mined land. The St. Leo plantings were really a dress research rehearsal for a larger planting on a clay-settling pond.

In the summer of 1994 five 8 ft.-wide grass strips were sprayed with glyphosate and mechanically rototilled two times (May and August) on a sloping site with sandy soil owned by St. Leo Abbey. Three hundred pounds per acre of an 0-10-20 with micro-nutrients were applied using a hand-held spreader. The pH of the soil was 6.0. The strips were 100 meters long. Alleys of 15 feet in pangola grass (*Digitaria decumbens)* were left between each strip. Irrigation drip tape was laid down and four Reps of equal length marked off. Four of the five hedgerows were planted with different Leucaena accessions from the UF holdings: K636, K340, McCarty Giant and Mott. The fifth hedgerow contained one Rep of K28, one Rep of a *L. pulverulenta* hybrid ("Soffes"), and one rep of PI 370749. The last Rep was planted to three PI's: K647, K67, and K618. All seed was scarified using the four-second boiling water method, inoculated and planted on August 9, 1994. Three rows per hedgerow were planted. A between-row spacing of 39 inches was used while furrows were made by hand using a hoe. Seed were planted by hand at 2 to 3 per inch and covered with less than one inch of soil. Germination was normal (10-18 days) and an assured stand (above the weed canopy) achieved by the end of 1995 or after 1.5 growing seasons. Only one accession, K 647, did not germinate; it was replaced the following year by the Hutton "Hybrid."

Initial growth, however, was slow due mainly to weed competition. Each year a frost removed the accumulated biomass. No yield data were taken until 1998 when a harvest of subplots was conducted. This first harvest of all the varieties, to date unreported, yielded 22 dry tons per acre of mostly wood (6). Harvesting has always been carried out with chain saws and machetes; stems being severed at an 18-20 inch height above the ground. Over time the stems became larger and the population gradually reduced. A final stable plant population in 2002 was determined.

For the present work, K636 was harvested in August, 2001, using a hand lopper as the stems were quite thin (approximately 1"). The leafy, 6-foot tall stems were severed as in previous years at 18-20 inches. The middle row of the hedgerow was used to harvest 7 linear feet of stems from the four Reps. The leafy portion was separated by hand from the stems and each fraction weighed fresh. The entire leafy fraction was dried for dry weight percent while a sub sample of the stem fraction was apportioned for drying.

The other site on clay soil is 57 miles south of St. Leo. On a 400-acre reclaimed clay pond called "P-1" by the owner, IMC-Global, preparation began in May of 1998, with a complete burn of the pond. Approximately one third of the pond had been "bedded" and ditched previously by IMC's land manager, J. Ackerly, by trenching parallel 2000 ft.-long ditches 80 ft. apart. These beds were pocked marked by numerous low spots, which were quite dry in the summer of 1998. No land leveling was carried out. Each bed measured 2000 ft. in length.

To reduce the quantity of seed required as well as the amount of herbicide used, a hedgerow system of planting was laid out. Two hedgerow widths were employed: 5ft. and 10ft. The 5-ft. hedgerows were employed on the 80 ft.-wide beds with five hedgerows per bed. Twelve beds were prepared. The young cogon grass in the future hedgerows was sprayed in August of 1998, with a 5% glyphosate solution using cone nozzles and 60 gallons of water per acre. Following die back, the leafy cogon grass was burned. Cogon grass alleys of equal width were left unsprayed, unburned and unplanted between the hedgerows. In effect 50% of the bed and non-bed areas was planted.

Seed was imported from Boi Gordo Seed Company in Campo Grande, the capital of the state of (South) Matto Grosso, Brasil. The three, "Forte" and "Texas", and "Hybrid", were held by the USDA in quarantine at the Miami airport for three days. The seed was four and five years old and was a bulk blend of all three lines. Because of its age, no scarification was thought necessary; germination, checked by both Bio Gordo and Cosaf beforehand, was low - between 50% and 60%. The seed had been stored under an open-air shed and was apparently affected by the high summer temperatures and humidity of western Brasil.

In September, thirty to forty pounds of seed per acre were drilled in 40 acres of clay using a Tye no-till planter. The Tye No-till Drill plants 10 eight-inch rows. For the 5-ft. hedgerows, only 5 rows were planted. In the 10-ft. hedgerow, 10 rows were planted. Modifications had to be made to the planter: the openers became clogged immediately in the wet clay soil and were removed. Since the large front-mounted, fluted coulter opened a nice furrow, the seed tube was merely extended and dropped to 6 inches above soil level. Planting depth was less than one inch. The rubber press wheel was also removed because the seed began to stick to it. Instead, a slatted, wood drag was used to roughly cover the seed. Fresh Leucaena inoculum was applied to the seed in an electric mixer using milk as a sticker. Planting was carried out on September 7th and 8th, , using a 60 horse power tractor and experienced operators from Lewis Farms. Germination took 14 to 18 days and thanks to timely rains immediately after planting, an excellent stand was achieved throughout the 40 planted acres.

Leucaena seedlings were subjected to a mild frost only once during the following cool season. The stems had become woody enough that most of the population survived. By midsummer of 1999, a thick canopy under each hedgerow was in place (see Figure 1). Growth was spectacular though no measurements were taken during the two years. In 2000 a mechanical harvest was carried out using a New Holland forage chopper.

For this study, yield was measured in February, 2002, one month following a light ground frost. Leaves were sparse. Four Reps were chosen in 4 different, parallel hedgerows eight feet wide. An 8 x 6-ft. block was cut from each Rep at 6 inches from the ground with a hand lopper. The whole plot was divided in two and weighed; a sub-sample was removed and weighed for further analysis. Total stem number and height was also measured. The fourth rep could not be harvested due to a sudden shower.

Finally, a 10-acre nursery/seed orchard was planted on another section of the P-1 clay area in August, 1998. Over 40 accessions from the GWC and Cosaf St. Leo nurseries were used. The results of this germplasm transfer to clay will be reported on another occasion in this Journal by the authors.

RESULTS AND DISCUSSION

By 1999, Cosaf had transferred from the GWC 40 Leucaena accessions to both St. Leo Abbey and the mined lands and planted three Hutton varieties mechanically on clay soil in a commercial pilot. It thus achieved its intended development of germplasm resources and production experiences. The “wood grass” at St. Leo Abbey could now be compared to “wood grass” under more commercial conditions on clay. In each case plant populations approaching 100,000/acre were initially obtained with leafy stems harvested at least twice a year or heavier and taller stems harvested after one year’s growth.

Figures 1, 2 and 3 show giant Leucaena on clay: Figure 1 shows the Hutton varieties 6 months after being planted on clay. Figure 2 shows the same Hutton varieties as in Fig. 1 on the 10 ft.-wide hedgerow at one year. Figure 3 shows McCarty Giant on wide spacing at four years. Figure 4 shows K636 hedgerow in regrowth mode at St. Leo (sand).

Figure 1 (on clay)

Figure 1. In first spring, flowering took place. No viable seed were produced.

Figure 2 (on clay)

Figure 2: The Hutton varieties in their second year produced no flowers.
If harvested, flowers and seed are not produced in closely spaced stands.

Figure 3 (on clay)

Figure 3: Widely spaced McCarty giant in Fall produced abundant seed on clay in the third year. Trees are 30 to 40 feet tall.

Figure 4 (on sand)

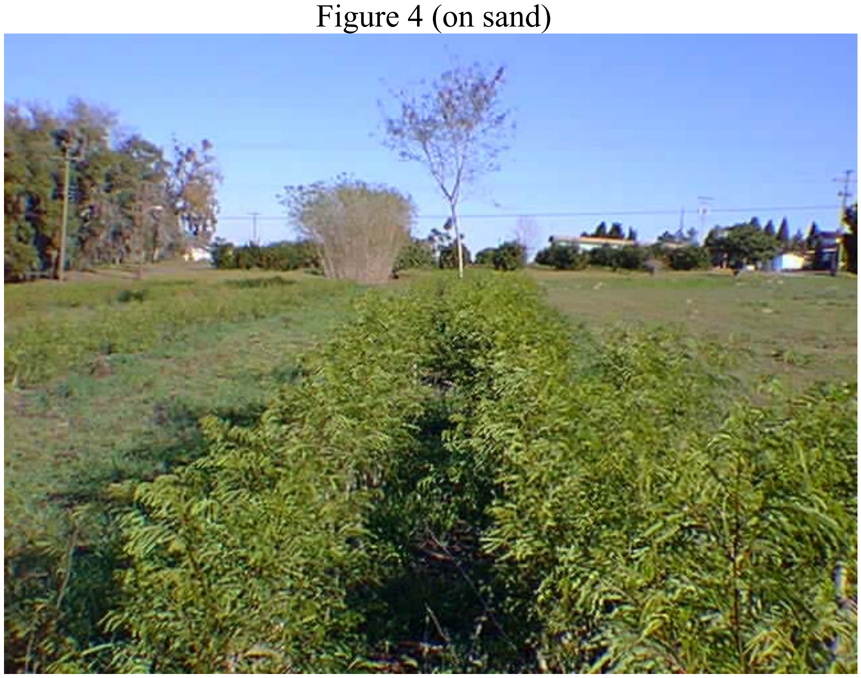

Figure 4: K636 hedgerow at St. Leo in regrowth stage following a 1998 harvest. Note trees in adjacent hedgerow and grass alleys. Seed is produced every year since stand was four years old. The individual tree in hedgerow is Cosaf Select.

Tables 1 to 6 present yield data for both sites.

TABLE 2: LEAFY K 636 AS GREEN MANURE FOR METHANE ENERGY ON SANDY SOIL

SAMPLE ID	N	C	C/N RATIO	CH_4 in Btu/acre (from anaerobic fermentation)
	%	%		
REP I	3.30	45.80	14:1	119 x 10^6
REP II	3.10	45.50	15:1	62 x 10^6
REP III	3.50	46.60	13:1	113 x 10^6
REP IV	3.20	46.70	15:1	70 x 10^6
AVE.	3.28	46.15	14:1	91 x 10^6

TABLE 5: Giant LEUCAENA AS DRY-WOOD FEEDSTOCK FOR THERMALLY COMBUSTED ENERGY ON CLAY SOIL

SAMPLE ID	N	C	C/N RATIO	BTU/acre (at 7,000 btu/lb. DM)
	%	%		
REP I	0.45	45.5	100:1	138×10^6
REP II	0.41	46.0	111.1	159×10^6
REPT III	0.62	45.7	74.1	256×10^6
AVE.	0.49	45.7	95.1	184×10^6

TABLE 1: YIELD OF 7-YR.-OLD K 636 HARVESTED AS GREEN MANURE ON SANDY SOIL AT ST. LEO, FL

SAMPLE ID	PLOT FW	DM	FW	FW	LEAF + STEM
	lbs.	%	t/acre	Mg/ha	dry t/acre
REP I	39.9	34.8	41.4	92.7	4.5 + 9.9
REP II	20.6	36.4	21.4	47.9	2.1 + 5.7
REP III	37.7	36.6	39.1	87.6	3.4 + 10.9
REP IV	23.4	43.2	24.3	54.4	2.3 + 8.2
AVE.	30.4	37.8	31.6	75.3	3.1 + 8.7

TABLE 4: YIELD OF 3-YR.-OLD Giant LEUCAENA HARVESTED AS WOOD ON PHOSPHATIC MINED-LAND CLAY

SAMPLE ID	PLOT FW	DM	FW	DW	DW
	lbs.	%	t/acre	t/acre	Mg/ha
REP I	75.1	29	34	9.9	22.2
REP II	69.7	36	31	11.4	25.5
REP III	84.1	48	38	18.3	41.0
AVE:	76.3	38	34	13.2	29.6

TABLE 3: TISSUE ANALYSIS OF LEAF AND STEM OF K 636 GROWN AS GREEN MANURE ON SANDY SOIL AT ST. LEO, FL

SAMPLE ID	P	K	Ca	Mg	Zn	Mn	Cu	Fe	Al	B	Ba	Mo
K 636	……….%……………				..……………ppm………………….							
REP I	0.20	1.60	1.4	0.51	20	19	4.5	94	19	43	15	0
REP II	0.17	1.54	1.1	0.53	19	19	5.0	90	24	36	14	0
REP III	0.21	2.14	1.1	0.42	34	26	5.5	100	22	39	17	0
REP IV	0.21	1.85	1.0	0.51	22	26	6.5	165	24	36	14	0
AVE:	0.20	1.78	1.2	0.49	24	23	5.4	112	22	39	15	0
K636 (stem) Ave. of 4 Reps	0.1	0.8	0.3	0.13	13	5	2.5	154	10	7.5	5	0
Adequate levels	0.2	1.0	0.5	0.2	20	50	6	100	--	20	--	1

TABLE 6: TISSUE ANALYSES OF WOODY Giant LEUCAENA GROWN FOR BIOMASS ON CLAY SETTLING POND SOIL

SAMPLE	P	K	Ca	Mg	Zn	Mn	Cu	Fe	Al	B	Ba	Mo
	……....%	……….			…………….ppm	………………………						
REP I	0.09	0.70	0.31	0.07	12.5	7.5	2.0	248	13	5.5	1.0	2.0
REP II	0.11	0.94	0.31	0.07	9.5	4.5	2.5	107	13	6.0	0.0	2.0
REP III	0.13	0.96	0.49	0.09	15.0	15	3.0	199	16	8.0	0.5	3.0
AVE:	0.11	0.87	0.37	0.08	12.3	9.0	2.5	185	14	6.5	0.5	2.3
Adequate levels	0.2	1.0	0.5	0.2	20	50	6	100	--	20	--	1.0

TABLE 7: AVERAGE MACRO NUTRIENT CONTENT OF GIANT LEUCAENA GROWN FOR GREEN MANURE ON SAND AT ST. LEO, FL

SAMPLE ID	N	P	K	Ca	Mg
	………….lb./dry ton…………….				
AVE:	**65.6**	**4.0**	**35.6**	**24**	**9.8**

TABLE 8: AVERAGE MACRO NUTRIENT CONTENT OF GIANT LEUCAENA GROWN FOR WOODY BIOMASS ON CLAY SETTLING POND SOIL IN POLK COUNTY, FL

SAMPLE ID	N	P	K	Ca	Mg
	…………...lbs/dry ton……………				
AVE:	**9.8**	**2.2**	**17.4**	**7.4**	**1.6**

Due to the high agronomic yields recorded on sand and clay, this data will be discussed mainly from the point of view of the industrialization of giant Leucaena to energy and byproducts. Notwithstanding the question of sustainability of yield over time counted in years, the necessary steps for industrializing this crop are placed, we believe, in clearer focus than ever before with this discussion. We will not consider the traditional thermal combustion of giant Leucaena wood because in the humid, lower south, drying costs are probably too great. Instead, fermentation and gasification technologies are considered in some detail. Both conversion technologies make use of a high moisture feedstock.

Tables 1, 2 and 3 treat the yield data from K636 on sand at St. Leo harvested in the middle (August) of the 2001-growing season. In Table 1, seven-year-old giant Leucaena yielded an average of 31.6 t/a. Of this total fresh weight yield, 34.1% is leaf. The dry matter leaf yield per acre averaged 3.1 tons; dry matter stem is 8.7 tons. A total DM yield then was therefore 11.8 t/a. Significant additional yield (in wood in particular) would be expected if harvest was delayed to November or December.

In Table 2, potential methane production from this material is shown. Driving the anaerobic fermentation process is nitrogen. Leucaena leaf contained 3.28% nitrogen. Its initial C/N ratio averaged 14:1. Following methanogenesis, this ratio would most certainly be reduced since carbon is converted to gas. Using conversions supplied by EcoWaste Management's J. Sifontes, the methane yield per acre will reach 91 X 10^6 Btu. This methane gas yield is determined using the following calculations.

1. 100 tons of biodegradable feedstock yields 480,000 scf of CH_4.
2. 31.6 t/a divided by 100 t x 480,000 = 151,680 scf/a of giant Leucaena;
3. 151,680 scf/a x 600 Btu/scf = 91 x 10^6 Btu or 91 MmBtu.
   (Note: scf = standard cubic feet)

This yield in Btu of pure methane gas (CH_4) could translate, at current retail prices of $4.05/mmBtu to $368.55 per acre (this is a price paid to the producer by a utility). The energy content of giant Leucaena is only half the story in terms of potential farm income. Following anaerobic fermentation, there are 15.8 tons/a of dry volatile solids or compost that come out of the fermenter. This material will have been dried. What portion of the Btu's produced will be required to dry the compost to the normal 12% moisture is not yet known. It will affect final financial analysis. N-rich compost has a minimum value of $30/t in organic agriculture. Fifteen tons at $30/ton is $450. Combined with the gross value of the gas, an acre of fermented Leucaena could be worth $818. (Drying costs and over-all economic feasibility will be established in a paper by the authors to be published in 2003.)

In Table 3 we return to nutrient levels. It will be seen that green chop giant Leucaena has much more in primary nutrients than Leucaena as wood grass due, no doubt, to the presence of leaves. Though not shown, the above-mentioned 3.28% N content of the leaf represents 783 lbs of N per acre. We consider this a most significant number justifying, under certain conditions, a post harvest separation of leaf from stem.

The percentages for macro-nutrients in the leaf fraction represent 47 lbs of P, 420 lbs K, 283 lbs Ca and 115 lbs Mg per acre. The percentages for micro-nutrients represent not only above adequate levels for the Leucaena growth itself but a harvest (as surplus) of all micronutrients except Fe which seems to be limiting in the location in question. The approach taken then, fertilizing the perennial green manure crop in order to concentrate surplus organic nutrients, not only does not create any obvious problems for the compost for use in certified organic agriculture but it creates a probable positive energy balance in the methane gas produced.

Before discussing the wood-grass tables, one additional observation on the above data can be made. The 2001 dry matter yield of 11.8 t/a obtained in central Florida on sand is between the average dry matter yields of Othman in 1984 (14 t/a), and the authors' possibly low yield (8.6 t/a) in the 1995. The difference, however, is that the 2001 harvest was effected in the middle of the growing season (after 6-7 months of warm weather). The high yielding "Othman 12" in Gainesville had 9-10 months of warm weather growth. If two harvests of lower-growing material are possible in the early summer and late fall, sustainable yield would become a function of soil fertility (fertilization) and moisture.

Tables 4, 5 and 6 contain yield, energy content and nutrient levels of giant Leucaena ("wood grass') on settling pond clay. The stand was just over 3-years old and is of 3 improved varieties developed by M. Hutton. Table 4 shows that there was variation among plot fresh weights. This may be a function of stem number and stem size present in each plot: Rep III contained 51, Rep II had 34 and Rep I had 40 stems. Stem height was almost perfectly uniform at 15 feet. In small tree, commercial biomass plantings, this yield variation has been the rule and not the exception. A wild fire in February, 2001, most certainly affected total plant population. The plant population in 2002 was only 37,812 plants per acre. The Table 1 data also show, after considering dry matter percentages, fairly tight data for the dry weight yield.

This yield of 13.2 t/a DM was used in Table 5 to determine energy content. Since much of the plant is cellulose (45.7% carbon) after defoliation in February, we have used unpublished Leucaena calorimetry data carried out by the junior author in 1995 on 4-year old material from Gainesville to guide our calculations. The actual average figure in 1995 from 10 accessions was 7805 Btu/lb of dry weight. This compares with an 8269 Btu/lb figure for 8 year-old wood from Hawaii. We use 7,000 Btu/lb in Table 5 to remain conservative. Leucaena is considered a medium hardwood with a specific gravity of 0.54. If 184 million Btu's are indeed contained in one acre of giant Leucaena wood grass after one year's growth, how much of this energy is available in a man-made conversion system? The coal gasification process possesses the greatest efficiency of any system now utilized. Typically the maximum efficiency for a natural gas-combined cycle gasifier is 60% and can be attained; at the Polk Power Station (IGCC – integrated gasifier combined cycle) owned and operated by Teco Energy, efficiencies from coal of 40% are the norm (33% plant efficiency is the norm for modern coal-fired boilers). Therefore, only 73 million Btu's/acre would be useful in producing electricity. Referring to prices utilities now pay for coal ($43/ton) and plant efficiencies at converting this fuel to net

Btu/net kwh, a calculation of fair market return to the producer is made easier. (A coal-biomass alliance has been called for and transparency, otherwise known as honest dealing, will be required.) It would appear that a producer would be paid \$3.00/ MmBtu or \$218/Leucaena-acre to replace the same Btu's from coal. Is this enough to cover production costs and make a profit? Three dollars per million Btu represents only \$16.59/ton for the effective 73 MmBtu/acre. Again, the authors will present the economic feasibility of growing giant Leucaena in a paper in 2003.

To conclude, giant Leucaena green chop and wood grass may have greater yield and thus bioenergy potential on both sand and clay when planted at close spacing. As such it may provide a more manageable crop for harvesting with conventional machinery. Full season giant Leucaena as wood grass yields much more wood than leaf in sub-tropical Florida on both clay and sand. As a energy crop it can be both fermented and gasified without drying. Preliminary economic analysis indicates that, after accounting for the sustainability of fertility on clay, it may be best to continue developing both fermentation and gasification systems for leafy wood grass on clay settling ponds. On those soils, giant Leucaena, no-tilled into cogon grass and harvested twice a year in the spring and fall may be the most effective use of human and plant resources for the foreseeable future. It may also be a highly profitable method to restore mined land clay ponds infested with cogon grass to a natural environment. Legumes build soil. As a multi-purpose perennial legume tree, giant Leucaena's niche in Florida, via sustainable biomass energy farming systems, is slowly being established.

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