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ENVIRONMENTAL SUGARCANE: PROPERTIES AND PERFORMANCE AS AN INTEGRATOR SYSTEM FOR CROPS, LIVESTOCK, AND ENVIRONMENT

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ABSTRACT. Since 1985 environmental conservation studies have centered on the *Saccharum spontaneum* cultivar US 67-22-2, a BC_1 hybrid of the *S. spontaneum* parent *Paseorean*. Bred in Louisiana as a sugar system, and imported as a parental line for the AES-UPR sugarcane breeding program in 1975, this cultivar has displayed remarkable potentials as a commodities integrator system that closely accommodates modern precepts of low-input sustainable agriculture. Outstanding properties include high productivity with minimal inputs, extended longevity of original plantings (at least 18 years), massive depositions of organic residues, a deep root profile, self weed and erosion control, high tolerance of drouth and flooding, an expansive green-leaf canopy (photosynthetic atmosphere conservation), and dense shelter for wildlife conservation. By 1991 sufficient experience had been gained to employ US 67-22-2 as an *integrator* system in a model wetland conservation farm enjoining together crops, livestock, wildlife, and precepts of environmental conservation and regulations compliance. In this capacity it serves as a whole-plant greenfeed for livestock, compost and fertilizer for food crops, weed and erosion control agent for seasonal crop seedbeds, wildlife conservation areas, and photosynthetic conservation of atmosphere. US 67-22-2 has assumed the common name *"environmental sugarcane"*, and locally also *"la caña de agua"*. Properties and current studies of *environmental cane* are presented herein.

INTRODUCTION

Environmentalism

A New Dimension for Agriculture: For Caribbean food crop planters the new millennium is bringing new challenges and opportunities of a nature unexampled in historic agriculture. Foremost among them is the *environmental movement*, an awakening awareness of the natural world and its conservation needs in a world rapidly filling with people (20,29,34,31,24).

The strength, pervasiveness, and finality of *"environmentalism"* would have astonished the food and sugar crop planters of Caribbean history. It embraces everyone who can read, view television, and vote. It affects all who utilize food, fiber, water and air (20,24). In this it is an utterly *affirmative* movement. And thus it will survive as long as humanity survives.

Without question, the modern entry of concerned public interest into the management of agricultural resources and affairs complicates farming. Environmental laws today can allow or disallow farmers the use of their own property (22,25,37,32). The Federal statutes and regulated programs that foreshadowed the work described herein apply to agriculture where practiced under U.S. Congresional jurisdiction. But in principle they are germain to the general Caribbean area. The U.S. *Clean Air* and *Clean Water Acts*, the *Food Securiy Act*, the *Shorelines Management Act*, the *Endangered Species Act*, and many others will inevitably find counterparts in concept and intent that overshadow future Caribbean agriculture.

Compliance, Integration, And Environmental Cane: "Compliance" is perhaps the most relevant word to describe environmental farming of the next century. It is all-inclusive. It carries the force of legal statutes, eligibility for farming entitlements and programs, and good common sense (21,22,28). The responsible food crops planter of the next century will operate in ways that preserve his farmland and environment for the next cropping season, the next generation, and the next century.

Non-Compliance in an era of enforced regulations would mean termination of the farming livelihood for some planters. Those already considering retirement or having only marginal operations could retire or sell their holdings to other farmers. This is a negative but natural process in any era. Another option is sale of farmland to non-agricultural interests, that is, for industrial or residential development and the *"mitigation"* of such development in concert with environmental precepts of *"no net loss"*. Equally negative is the voluntary enlistment in *"restoration"* programs designed to return farmland to its pristine state in behalf of wildlife. The latter are in fact a significant threat to wetland farming at the author's own properties in Washington State (38,28,26). A fourth option, and commonplace where regulations enforcement has begun, is to continue farm operations essentially as in the past, assuming added costs of compliance where convenient and risking fines and entitlements eligibility loss where not convenient. No true agriculturist should find comfort in any of the above options (12,39).

A far better alternative is *integration*, that is, the attainment in common of agricultural and conservation interests in one and the same enterprise. By *"integration"* is meant the design and conduct of farm operations by ways and means that comply with environmental laws, that enjoin together precepts or farmland and environment conservation, and that encourage the continued farming livelihood of agricultural landowners (39,15,37). In the view of the author, both conceptually and tactically, the Caribbean is better suited for environment-integrated farming than any region of the U.S. mainland (18,19).

The integration of agricultural and environment-conservation technologies has been investigated by the author in Puerto Rico since 1986. Originally motivated in part by the enforcement of U.S. environmental laws at the author's wetland farms in Washington State, the Puerto Rico work dovetailed mainland developments in the ensuing 11 years. Progress has been slow but steady.

Nonetheless the work that has been done here gained materially from prior experience with sugarcane and other tropical grasses. AES-UPR was mandated as a sugarcane research institution at its founding in 1910. The author had already accrued 23 years experience with sugarcane when its environment-oriented potentials came under investigation in 1986. Thus, although unofficial, the AES-UPR environmental research that began in 1986 was squarely centered on original AES mandates for vigilance and innovation in behalf of sugarcane.

Inevitably, the ancient genus *Saccharum* seemed preordained to accommodate modern precepts of environment-oriented agriculture (36,19). An outstanding example has emerged in the *S. spontaneum* cultivar US 67-22-2, a BC_1 hybrid of the *S. spontaneum* parent *Paseorean*. Bred in Louisiana as a sugar system, and imported as a parental line for the AES-UPR sugarcane breeding program in 1975, this cultivar has displayed remarkable aptitudes for biosphere conservation in virtually all contexts and from all points of view. In the years 1986-1991 the author was repeatedly astonished by its resilient productivity and self-sustaining properties. They seemed direct answers to the accommodation needs of environmental regulations enforcement already underway at that time on the U.S. mainland.

By 1991 cultivar US 67-22-2 had assumed the name *"environmental cane"* in Puerto Rico. It was no longer regarded as a sugar system, or even solely a high-growth biomass system. Its far more relevant potentials as an environment-conservation and integrator system were established beyond reasonable doubt (13,17,9,19). These potentials appear germaine to the environment-oriented future of Caribbean agriculture, while at the same time offering a discrete detachment from nearly 3,000 years of cane sugar planting (13,30,33,1).

MATERIALS AND METHODS

From 1986 to 1991 the work with US 67-22-2 was neither a single experiment nor a closed-loop study with fixed goals from the outset. It was rather an evolved sequence of field experiments, established in concert with new properties and potentials of US 67-22-2 emerging under low-input and environmental-compliance regimes (12). Our general objectives were:

- To determine US 67-22-2 capabilities for compliance with the U.S. *Clean Air* and *Clean Water Acts*, the *Food Security Act*, and conservation provisions of U.S. Farm Bills.
- To determine whole-plant productivity with irrigation, fertilization, and pest control inputs restrained, including reduction to zero.
- To determine longevity and self-renewal capabilities of original US 67-22-2 plantings.
- To evaluate whole-plant and plant residues performance in weed and erosion control, as organic fertilizer and compost, as greenfeed for livestock, as habitat for wildlife, and active greenleaf surface for photosynthetic atmosphere conservation.

Cultivar US 67-22-2 is a BC_1 hybrid of the *S. spontaneum* parent *Paseorean*. It was bred and selected by Dr. P. K. Dunckleman and colleagues at the USDA Sugarcane Field Station, Houma, Louisiana. Mr. T.L. Chu, sugarcane breeder with the AES-UPR sugarcane breeding program, visited Houma in 1975 in search of new parental lines. He was offered his choice of available materials for importation to Puerto Rico. Some 30 cultivars were selected. These included US 67-22-2 which already had displayed remarkable properties as a vigorous growth system. The author regards its original selection from a sugar-oriented program and its importation to Puerto Rico as milestones in the modern history of sugarcane agriculture.

In 1979 a half-acre block of US 67-22-2 was planted at Hacienda Santa Rosa, a privately owned lowland farm near Hatillo on Puerto Rico's semi-humid north-central coast. This planting still prospers in its seventeenth ratoon crop year. In 1985 seed from this block was used to plant 18 acres on the same farm. This was the site of some 14 experiments from 1986 to 1991, and of observational studies that continue to the present (12). In 1993-94, and again in 1996-97, additional plantings were made on a wetland site adjoining Santa Rosa.

Hacienda Santa Rosa is situated in the Camuy River Valley on alluvial soils deposited by river flooding over thousands of years. The principal soil Series is *Coloso Silty Clay* which overlies at least two lower Series of uncertain identity. Except for the most elevated lands adjoining the river, virtually all of the Camuy Valley conforms to current U.S "Wetlands" or *"Prior-Converted Wetland"* (PC) classifications. Average annual rainfall is 51.2 inches.

Original planting and management methods are described elsewhere in detail (9,19). These were oriented to high-tonnage production of whole-cane biomass as practiced in the 1970's and early 1980's with commercial sugarcane hybrids. They emphasize *attention to detail* in seedbed preparation, planting, irrigation, and fertilization in multiple increments. However, from 1987 onward such inputs were cut back drastically as self-sufficiency features of US 67-22-2 emerged. Some blocks have received no inputs at all since 1989. In more recent plantings only the special care in seedbed preparation and planting has been retained at previous levels. From about 14 weeks post-planting onward new plantings are essentially "on their own" without further inputs (19,9). For most experiments since 1987 the replicated small plot, previously about 600 square feet, has given way to unreplicated field plots one to four acres in size.

Whole-cane harvest methods, both mechanized and manual, are described in earlier publications (10,12,16). Also described are procedures for plant partitioning, root zone excavation and assessment, and irrigation, drainage, and post-harvest seedbed management (10,12,19). Compost and organic fertilizer production from US 67-22-2 utilized conventional "flail" field choppers operating on pre-aligned whole cane. Consistent use of color photography has been maintained to the present.

Since 1986 the US 67-22-2 plantings at Santa Rosa have been afflicted by various stresses of nature. These included three hurricanes (*David, Hugo, and Hortense*), two severe drouths, one "decade" flood, and one "century" flood together with about a dozen small or moderate floods from the nearby Camuy River. In 1993-94 only 13.6 inches of rainfall were received. While inconvenient at the time such stresses and events have materially benefited our understanding of US 67-22-2 in environment-accommodating capacities.

RESULTS AND DISCUSSION

Conservation Attributes of US 67-22-2: The most *ideal* crop plant for Puerto Rico's future farmers would be no stranger to the island's past five centuries of sugarcane agriculture. Herein lies the Puerto Rican experience in farming and inarguably the most natural crop plant for Puerto Rico. The ideal plant would by nature and management adjust comfortably to the U.S. *Food Security Act*, the *Clean Air Act*, *Clean Water Act*, *the Food, Agriculture, Conservation And Trade Act* (FACTA), the *Endangered Species Act* (ESA), and conservation provisions of the U.S. Farm Bills.

By 1985 our experience with US 67-22-2 had already revealed some aptitude of this cultivar for accommodating environmental interests. During the next eleven years, US 67-22-2 emerged as a conservation farming resource that comes surprisingly close to the "ideal" crop plant described above. Salient features of US 67-22-2 as a conservation system include:

(a) ***Low-Input Productivity*****:** During the years 1979 to 1985, when US 67-22-2 was studied under intensive high-growth management, annual yields were routinely in the order of 90 to 125 tons whole cane per acre (4). The highest yield ever attained was 142 tons whole cane per acre in a *gran cultura* crop of 20 months duration. Under low-input management after 1985, with fertilization and irrigation reduced to zero, yield declined to 56 tons per acre in the first year and to 42 tons per acre the second year without inputs. In the third year and thereafter annual yields hovered consistently in the range 38 to 45 tons whole cane per acre year (5,8,19).

While yield reduction was remarkable the sustained productivity without inputs was more so. It exceeds that of the current P.R. sugar industry by a factor of two to three. The economic and environmental tradeoffs distinctly favor the grower. Yields in the order of 38 to 45 tons without inputs are definitely "acceptable". Because no chemical fertilizers or pesticides were now being used the planted site was on-course for long-term compliance with the *Clean Water Act*, the *Clean Air Act*, and *the Food Security Act*.

(b) ***Longevity Of Plantings:*** Equally important as sustained productivity is the extended lifetime of US 67-22-2 plantings. None of the US 67-22-2 experiments established since 1979 have needed replanting. This is attributed to *self-renewal* via underground shoot extension of the established parent crown, a botanic feature common to *"wild" S. spontaneum* varieties (9,19,4). But this ability was aided materially by a dense overhead canopy and heavy trash depositions that exclude competitor species from the area (9,14).

In the author's own experience as farmer and investigator, US 67-22-2 has been the only herbaceous crop plant that could sustain acceptable productivity for 18 years without human inputs and without need of replanting. The high costs of conventional sugarcane replanting at three- or four- year intervals are thus eliminated from the environmental cane enterprise.

Equally relevant is the exceptional suitability of such stands for conservation programs that encourage temporary retirement of farmland from production (28,26). These include the U.S. *Conservation Reserve Program* (CRP), the *Wetland Reserve Program* (WRP), the *Environment Quality Incentives Program* (EQUIP), the *Wildlife Habitat Incentives Program* (WHIP), and the *Wetlands MOA* (Memorandum of Agreement). In such programs farmland taken out of production on 5- or 10-year contracts are often reverting to a pristine cover state at contract termination. If can be costly to resume active production owing to trees, brush and perennial weeds established during reserve years. A US 67-22-2 planting at the outset would secure the area indefinitely while contributing massive organic residues to the reserve seedbed surface. These residues are not a crop but would be incorporated into the soil upon renewal of cropping activity. The same standing cane with accummulated residues is highly consistent with the wildlife habitation, erosion-control, and ecosystem preservation needs that such programs are designed to accommodate.

(c) ***Self Weed And Erosion Control:*** In studies since 1985 no herbicides have been used with US 67-22-2. Pre- and post- emergence treatments applied in earlier years were deemed unnecessary. Thereafter, owing to typically early green-leaf canopy closure in the plant crop, and heavy trash depositions in ratoon crops, weed growth was effectively suppressed. Only during the first 12 to 14 weeks of the plant crop were weeds a potentially serious factor, and these have been controlled as needed by non-chemical means (14,17) Non-use of herbicides is consistent with U.S. environmental laws compliance.

(d) ***Natural Stresses Tolerances*:** The ability of US 67-22-2 to remain acceptably productive without irrigation, fertilization, or grower intervention of any sort is interpreted as an inherent capacity to accommodate its natural biosphere unexampled in the hybrid sugarcanes of commerce (4,19,9). Any normally-productive commercial cane variety, given correct establishment and management during its plant crop year, and given fertile soil and adequate rainfall, might possibly produce a tolerable yield for one more year without grower inputs (4). But it could not sustain productivity through a second ratoon crop year, not to say 17 years as noted for US 67-22-2. Nor could it likely maintain a productivity worth harvesting if drouth, flooding, or hurricane damage occurred any time after zero-input cropping began.

The original US 67-22-2 plantings at Santa Rosa have survived without difficulty three hurricanes, two major drouths, three major floods and numerous lesser floods and "dry spells" over a time-course of 18 years. This is accountable only to an affinity for nature not widely known in the hybrid crop plants of modern agriculture. It is as well a testimonial for *Saccharum* as a genus prefigured for accommodating the regulated environmental agriculture of the twenty-first century and beyond (19,12,13).

(e) ***Environment-Oriented Botany***: Books could be written, and have been written (36,1), on the complex botany of sugarcane. These concern the internal operation of its anatomical, physiological, biochemical and biophysical features comprising an intact *source-to sink system*. However, newly-recognized features of US 67-22-2 as an environment conservation system add a whole new dimension to our understanding of *Saccharum* botany as related to its external biosphere (19). Some salient features are presented in the following text.

A most decisive botanic "first" of US 67-22-2 is its massive foliar canopy. It comprises on the average some nine to twelve active green-leaf blades and their subtending leaf sheaths (14,9). The adult stems of conventional sugarcane hybrids rarely bear more than five or six such leaves. Older ranks are generally undergoing chlorophyll loss, physical or structural damage, and injury from "ringspot" and other diseases common to aging cane foliage. The deep, dense, green-leaf canopies of US 67-22-2 plantings are striking even to the layman observer. They are crucially important as the site of photosynthesis while ultimately forming the "trash" residues already discussed as weed and erosion control agents.

A second feature setting US 67-22-2 apart is its *biannual growth* habit, that is, the annual production of at least two sets of stems from the same stool complex (11). Primary shoots ordinarily experience an early rapid flush of growth with remarkable internode expansion up to month five or six. Thereafter there is little additional growth of original stems but a second set of shoots emerge and these also largely complete their growth by month 12. Elements of a third set are commonly visible by that time.

The sugarcanes of commerce are not managed to produce two crops per year nor are they botanically inclined to do so. Some 14 to 18 months are commonly required to optimize sugar yield in sugar-oriented varieties. But the environment-conservation functions of US 67-22-2 are that of a *growth* system not a *sugar* system. The biannual growth habit of US 67-22-2 materially increases its flexibility and range of application in performing conservation roles (11). This is particularly true when a given planting, or any planting in a given crop year, is intended for harvest as a livestock greenfeed, compost, organic fertilizer, or erosion-control agent for seasonal food crop seedbeeds.

A third botanic feature is the capacity of US 67-22-2 for *crown self-renewal*. As a contributing factor in the extended longevity of its planting, this feature is botanically characteristic of "wild" *Saccharum* species (36,30). Its retention by a *S. spontaneum* hybrid suited both for cultivation as a farm commodity and an environment conservation system is a happy coincidence indeed (19).

A fourth botanic feature, one that is apparently rare within *Saccharum*, is its ability to form a *deep and expansive root profile* (9,6). At Santa Rosa the author has made numerous excavations to depths up to seven feet without reaching a depth limit for root development other than the site's normal water table. At Santa Rosa such root growth achieved penetration through several discrete soil *Series* layered vertically, one above the other. Without question this affinity for root growth to great depths must contribute to the plant's self-procurement of water and nutrients. As much as anything this feature must underwrite its continued high productivity when all external inputs are withheld (9).

A fifth botanic feature is *disease and insect tolerance*. The use of pesticides on food crops has come under criticism in the environmental age more that any other practice of modern agriculture (35,29,23). During our 18 years work with environmental cane no pesticides have ever been used or needed. The only disease commonly recurring is *ringspot* in aged leaves, generally in the order of leaf ranks 9 and older. This cultivar is resistant to *rust* and the much-dreaded *sugarcane smut*. Insects that attack US 67-22-2 are the *white grub* in roots and *cane borer* in above-ground stems. Alphids can be found seasonally but never at levels of concern. US-67-22-2 is probably not botanically *resistant* to pests. Rather, its vigorous growth habits appear to render tolerable any impacts by traditional *Saccharum* pests (9,17).

A sixth feature is *fertility enhancement* of the occupied site. Although still a working hypothesis the evidence for this is compelling and mounting each year (17,8,12,5). Because much of the nutrient supply sustaining US 67-22-2 under zero-input management originates at comparatively great depths that are wholly inaccessible to shallow-rooted crop plants, and because an important fraction of these nutrients is reincorporated at the seedbed surface as the trash residues deposited there decay, a natural "recycle" system has been hypothesized and, for lack of better terms, is called *"Biological Subsoiling"* (18,19,9). But this is more than mere recycle. The deep and pervasive root system, procuring from depths up to seven feet or more, must bring into active agriculture nutrients that are otherwise inaccessible to shallow-rooted species that would occupy the site in planned rotations with environmental cane (5,8).

Fertility "enhancement", or fertility "renewal", or "soil rehabilitation", whatever it is called, is of enormous importance for conservation-oriented agriculture. Its is of equal importance in contexts of farmland *sustainability*, that is, sustainment of productivity from year to year, generation to generation, and century to century (7,17). The ability of US 67-22-2 to procure water and nutrients from otherwise untapped nearby resources is a very good thing, highly consistent with the *Clean Air* and *Clean Water Acts*, the *Food Security Act*, and other statutes that favor the reduced usage or non-use of agricultural chemicals.

The botanic feature of greatest relevance to the *Clean Air Act* is the exceptionally large and active *green-leaf surface* of established US 67-22-2. This area is in the order of 4 to 5 times that of the planted seedbed (9). Photosynthesis operating in the cane leaf canopy is the mechanism that provides carbon and energy to sustain all life processes of the cane plant. *Saccharum* photosynthesis is comparatively proficent in this (19,2.3). Through removal of carbon dioxide from the atmosphere and release of oxygen to the atmosphere, in relatively great quantities on a year-round basis (2,3), the greenleaf surface of environmental cane contributes to *"atmosphere conservation"* (9,18,13). Some 5 to 7 tons carbon per acre are estimated to be sequestered annually from US 67-22-2 given zero-input management (19).

Environmental Cane In Perspective

"Back To The Future": Although bred in the 1960's, there is compelling evidence that US 67-22-2 is not really a product of our time. All our experience with this cane points to the conclusion that it is a modern embodiment is one cultivar of botanic attributes that enabled *Saccharum* to survive since the early *Cretaceous* epoch. While today's sugarcanes of commerce are largely a product of breeding and selection for *sugar* attributes over the past 90 years, the genus itself is unimaginably old and hardened by experience in matters of survival. Nearly two-thirds of its earthly tenure was shared with dinosaurs. Its great botanic attributes are not of sugar planting but of *growth* and *survival*, and its botanic fixation is on a 200-million years old biosphere that was constantly changing and severely competitive for evolving plant species (19).

Environmental changes in that interval include the botanically-luxurient *Mesozoic* era, with warm-climate species extending far to the north of their present latitudes. They bordered warm inland seas untempered by cold deep-sea currents. Atmospheric CO_2 levels were 8 to 16 times greater than that of today (27). Growth competition among neighboring species for sunlight, space, water and nutrients was unrelenting (1,30). This golden age for earth's botany foreshadowed the climatically-severe *Pleistocene*, a biosphere-traumatic epoch of low temperature and glaciation that brought extinction for thousands of plant and animal forms. Environment accomodation and survival under stress is nothing new for *Saccharum*.

The portfolio of cane botanic and agronomic attributes described in this paper is neither accidental, unilateral, nor wholly self-serving. It derives from ineffacible processes of *Saccharum* improvement operating in unimaginable expanses of time. Viewed in this perspective the input restraints on environmental cane in the interests of compliance conservation farming seem modest indeed. The relative ease by which US 67-22-2 adjusts to non-replanting, non-use of irrigation, non-use of chemical fertilizers, non-use of pesticides, self weed and erosion control, and abstemious of human inputs in general is eloquent testimony to botanic vigilance and innovation under stress conditions (9,19). Most crop plants of contemporary agriculture could not survive, not to say remain economic, if given comparable production constraints.

Integration

A New Role For Sugarcane: Since 1979 US 67-22-2 has performed remarkably well under imposed stress conditions tantamont to grower abandonment of normal production inputs. Having learned this an important question arises: What is to be done in future with a plant so accommodating of environmental interests and so productive even under the most abstemious of grower management regimes? One answer is to *"harness"* it with food crops having no such aptitudes.

Food crop species having lesser growth and self-sustainment properties might perform acceptably well if produced in concert with environmental cane. By this is meant production of US 67-22-2 on the same farm for use on the same farm to bring all farm operations into compliance as a regulated sustainable farming enterprise. This has been the keystone goal of environmental cane work in Puerto Rico since 1991 (15,18,19). In this capacity the cane component, or *"subsystem"*, becomes an *integrating* factor that can tie together all subsystems with the farm's natural biosphere (15). If offers a source of greenfeed for livestock, of organic fertilizer for food crops, of massive residues for weed control, erosion control, and fertility enhancement in seasonal food crop seedbeds, of atmosphere stabilization for the ambient area, and dense habitat for wildlife. In Puerto Rico the environmental cane subsystem would also be the integrated farm's component most suited for participation in land and wildlife conservation programs, for example, the U.S. Federal CRP, WRP, MOA, EQIP, WHIP, and FPP programs (28). This is no small portfolio for a single crop plant in an era of regulated conservation agriculture.

For investigators like the author who have worked a career lifetime with sugarcane the natural potentials of ancient *Saccharum* to accommodate modern *environmentalism* come as no great surprise. That some extant cultivar can do so much so well is surprising. Yet apart from this the evidence for accommodation is compelling. It is convincing to all who have bothered to examine sugarcane as a non-sugar growth system and biomass commodity (4,12,13). Viewed objectively, a future role of *Saccharum* as an integrating factor in environment-integrated agriculture is clearly indicated (12,13,15,17).

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