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Nutrient Accumulation and Removal by Sugarcane Grown on Everglades Histosols

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ABSTRACT

Sugarcane (interspecific hybrids of *Saccharum* spp.) is Florida's most valuable agronomic crop. Recently, sugarcane production has come under scrutiny because of concerns regarding the impact of nutrient-rich drainage water on the ecology of adjoining bodies of water and wetlands. The objective of our research was to define the N, P, K, Ca, and Mg seasonal accumulation patterns in the aerial portion of sugarcane grown on organic soils of the Everglades Agricultural Area. Sugarcane fields were sampled on 30 to 60 d intervals during the plant-cane and first-ratoon crops. Dry weight, N, P, K, Ca, and Mg accumulation were determined and characterized by logistic growth models. Dry weight accumulation averaged 0.15 t ha^{-1} d^{-1} during the grand growth period. The period of most rapid nutrient uptake was shown to correspond with the grand growth period and the rates of nutrient uptake during different phases of crop development were defined. At harvest, 71% of total dry matter and 55, 63, 64, 25, and 38% of total accumulated N, P, K, Ca, and Mg, respectively, were removed from the field as millable sugarcane. Phosphorus and K removal from the field by crop harvest was equivalent to 179 and 201%, respectively, of added fertilizer P and K. Apparently, fertilizer P and K were minor contributors to the total soil pool of plant available P and K. Nutrient accumulation patterns should be incorporated into future management plans designed to minimize the impact of sugarcane production on the surrounding environment.

SUGARCANE is Florida's most valuable agronomic crop. In 1990, 87% of the 178 000 ha sugarcane crop produced in Florida was grown on Histosols (Coale and Glaz, 1991). Recently, the Everglades Agricultural Area (EAA) has come under scrutiny by environmental, agricultural industry, and State and Federal government water management groups concerning the impact of nutrient-rich drainage water from organic soils on the ecology of adjoining bodies of water and wetlands (Izuno et al., 1991). Phosphorus has been determined to be the biologically limiting nutrient in neighboring Lake Okeechobee (Federico et al., 1981). Hence, the influx of P into Lake Okeechobee through agricultural drainage has been proposed as a contributing factor to the lake's accelerated eutrophication (LOTAC I, 1986). Additionally, P from agricultural drainage entering adjacent wetlands has been alleged to be causing a transition from native plant species such as sawgrass (*Cladium jamaicense* L.) to cattails (*Typha latifolia* L.) (LOTAC II, 1990). Efficient management of native and applied crop nutrients is essential for maximizing net returns from sugarcane production and for minimizing the impact of sugarcane production on adjacent non-agricultural areas.

Ayres (1936) identified variety, climate, crop age, soil type, and applied fertilizers as factors influencing the mineral composition of sugarcane. Sugarcane response to these factors has made tissue analysis for evaluation of crop nutrient status somewhat location specific. Still, alternative tissue testing procedures have been used effectively to monitor sugarcane nutrition in Hawaii (Clements, 1972), Puerto Rico (Capo et al., 1955), South Africa (Beaufils and Sumner, 1976), Louisiana (Golden and Ricaud, 1965), Florida (Elwali and Gascho, 1984), and other locations. Each tissue testing procedure utilizes the nutrient concentration of a diagnostic tissue or plant part to develop an index for monitoring crop nutrient status. However, none of these procedures provides a quantitative measure of nutrient accumulation during the growing season.

Sugarcane growth is generally characterized by a period of rapid biomass accumulation ("grand growth period", GGP), which corresponds to the near-linear portion of a sigmoidal growth curve. In Florida, the sugarcane production season is 11 to 18 mo, which is relatively short compared to sugarcane grown in the tropics. Accordingly, the length of the GGP is relatively short and the period of most rapid nutrient uptake has been shown to correspond with the GGP (Golden and Ricaud, 1963). However, the rate of nutrient uptake during different phases of crop development has not been defined.

The quantity of nutrient elements removed per hectare by sugarcane harvest has been investigated to help determine the necessary fertilizer additions for subsequent crops. Golden and Ricaud (1963) concluded that 0.72 kg N, 0.18 kg P, and 1.22 kg K t^{-1} millable sugarcane were removed from mineral soils in Louisiana. Andreis (1975) presented similar data (1.11 kg N, 0.16 kg P, and 1.67 kg K t^{-1} sugarcane) derived from sugarcane harvested from organic soils in the EAA. Golden and Ricaud (1963) presented a graphic description which suggested a general sigmoidal pattern of dry matter and nutrient accumulation during the growing season. These data are very useful but, still, the time-course of nutrient accumulation throughout the growing season has not been described by a model that may be utilized in future research or nutrient utilization management plans.

There is a lack of information on seasonal nutrient uptake by sugarcane grown on organic soils. A renewed emphasis has been placed on efficient nutrient utilization due to recent drainage water quality concerns. The objective of our research was to define the N, P, K, Ca, and Mg seasonal accumulation patterns for sugarcane. This information will be incorporated into developing best management practices for fertilization, drainage water management, and fertigation of sugarcane grown on organic soils.

MATERIALS AND METHODS

Plots for determining seasonal nutrient accumulation in sugarcane were established in two commercial sugarcane fields in the EAA ("locations"). Locations 1 and 2 consisted of four and eight 0.7-ha plots, respectively. Sugarcane was planted on

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1.5-m row centers using standard commercial practices. Location characteristics are presented in Table 1. Fertilizer was band-applied in the furrow at planting (1st crop) and surface broadcast after initiation of ratoon-crop regrowth (second crop). Fertilizer rates were determined by the cooperating grower and were based on pre-plant soil test and prior cropping history.

Sugarcane samples were collected on 30- to 60-d intervals during the plant-cane crop (1st crop) and first-ratoon crop (2nd crop) at both locations. Each sample was collected from a randomly selected site within each 0.7-ha plot. Stalk numbers per 30 m of row were counted on two adjacent rows. Total aerial biomass per 3 m of row was cut from two adjacent rows (9-m² area) and removed from the field. For ratoon crops only, final samples of sugarcane stalks were topped at the uppermost hard node and stripped of remaining leaves to simulate commercially harvested sugarcane. All leaves and tops removed from the stalks were retained and analyzed. Fresh weights of the topped and stripped ("clean") stalk samples were recorded. All plant material was coarsely chopped with a gasoline powered garden mulcher, thoroughly mixed, and weighed. A subsample (approximately 1 to 2 kg) was collected, weighed (fresh weight), dried at 60°C until constant weight, and weighed. Fresh weight of the entire chopped sample, and fresh and dry weights of the subsample were used to calculate the dry weight of the entire sample. Dry subsamples were ground to pass through a 0.85-mm screen. A 0.3-g subsample of the ground plant tissue was digested by the sulfuric acid/hydrogen peroxide method described by Wolf (1982). Nitrogen and P were determined by ammonia-salicylate and phosphomolybdenum colorimetric procedures, respectively (Technicon Industrial Systems, 1977). Potassium, Ca, and Mg assays were conducted using atomic absorption spectrophotometry. Crop nutrient accumulation was calculated from total sample dry weights and plant tissue nutrient concentrations.

Raw sugar and molasses samples collected at a commercial sugar mill were analyzed as described above.

Statistical analyses were conducted using SAS PROC GLM and PROC CORR procedures (SAS Institute, 1985). Dry matter and nutrient uptake models were determined using the SAS PROC NLIN procedure. All models presented were highly significant ($P < 0.01$) descriptions of the data set.

RESULTS AND DISCUSSION

Dry weight accumulation by sugarcane was characterized by a logistic growth model (Fig. 1). The model included data from all locations and crops because the 95% confidence intervals for the models for single locations, crops, or combinations of location and crop overlapped. Therefore, dry matter accumulation models for any one location (L1 or L2) or crop (C1 or C2), or combination of location and crop (L1 C1, L1 C2, etc.) were not significantly ($P < 0.05$) different. In Florida, the GGP for sugarcane is usually defined as beginning 1 June (152nd day of year) and ending 15 October (288th day of year). Data collected over the four crop-years of our study corroborated this definition. Dry weight accumulation averaged 0.15 t ha^{-1} d^{-1} during the GGP. During this period of rapid growth, 64% of total crop dry matter was produced.

Sugarcane stalk population increased from planting until the beginning of GGP when a maximum stalk population of approximately 160,000 stalks ha^{-1} was observed (data not shown). During the GGP, intra-plant and inter-plant competition resulted in a decline in stalk number until a constant population of approximately 120 000 stalks ha^{-1} was established. This population was maintained until crop maturity. The pattern of seasonal change in stalk population described above was similar to that described previously by Shih and Gascho (1980).

Between 1000 and 1500 kg N ha^{-1} yr^{-1} are mineralized from Everglades Histosols (Terry, 1980). Sugarcane yield response to N fertilization has not been demonstrated and N fertilization is not recommended for sugarcane production on organic soils (Sanchez, 1990). Nitrogen accumulation by sugarcane closely paralleled biomass accumulation (Fig. 2). A single logistic model best characterized N accumulation over the four crop-years. During the GGP, N uptake averaged 0.67 kg ha^{-1} d^{-1} and accounted for 54% of total N accumulation. Average N uptake during the GGP was equivalent to only 15 to 20% of the estimated rate of soil N mineralization (Terry, 1980).

Positive yield responses to P and K fertilization of sugarcane grown on organic soils have been documented (Gascho and Kidder, 1979). Seasonal P and K accumulation were also described by logistic models (Fig. 3 and Fig. 4, respectively). Phosphorus and K uptake during GGP contributed 67 and 68% of total P and K accumulation, respectively. The K uptake rate was very high (4.14 kg ha^{-1} d^{-1}) during the first 60 d of GGP. Again, the 95% confidence intervals for the P and K accumulation models for any one location, crop, or combination of location and crop overlapped and, therefore, the overall model included all locations and crops.

Phosphorus and K fertilizers are applied at the time of planting for plant-cane crops and after initiation of ratoon regrowth for ratoon crops. For optimum sugarcane production on organic soils of the EAA, fertilizer applications of 0 to 37 kg P ha^{-1} and 0 to 233 kg K ha^{-1} are recommended, depending on soil-test extractable P and K determined prior to planting (Sanchez, 1990). Sugarcane P and K accumulation were relatively slow for several months following fertilizer application. Therefore, due to soil saturation and subsequent field drainage following heavy rainfall events, a potential exists for loss of applied P and K from the root zone during the early portion of the growing season (Izuno et al., 1991).

Table 1. Soil type, depth, and organic matter (OM) content, soil-test extractable nutrients, and sugarcane cultivar planting and harvesting dates at the two sampling locations.

Location	Soil type†	Soil depth	Soil OM	Soil test‡ pH	P	K	Fertilization§ 1st	2nd	Cultivar	Planting date	Harvest date 1st	2nd
		m	g kg^{-1}				kg ha^{-1}					
1	Lauderhill	0.72	839	6.4	8	220	0-7-110	0- 5-180	CL61-620	29 Dec 1988	18 Jan 1990	20 Dec 1990
2	Terra Ceia	1.63	816	7.1	6	99	0-0-162	0-21-168	CL61-620	20 Oct 1988	25 Jan 1990	30 Dec 1990

†Lauderhill muck = Euic, hyperthermic Lithic Medisaprists
Terra Ceia muck = Euic, hyperthermic Typic Medisaprists
‡Based on Sanchez, 1990. P=8 is high, P=6 is medium, K=220 is high, K=99 is medium.
§N-P-K

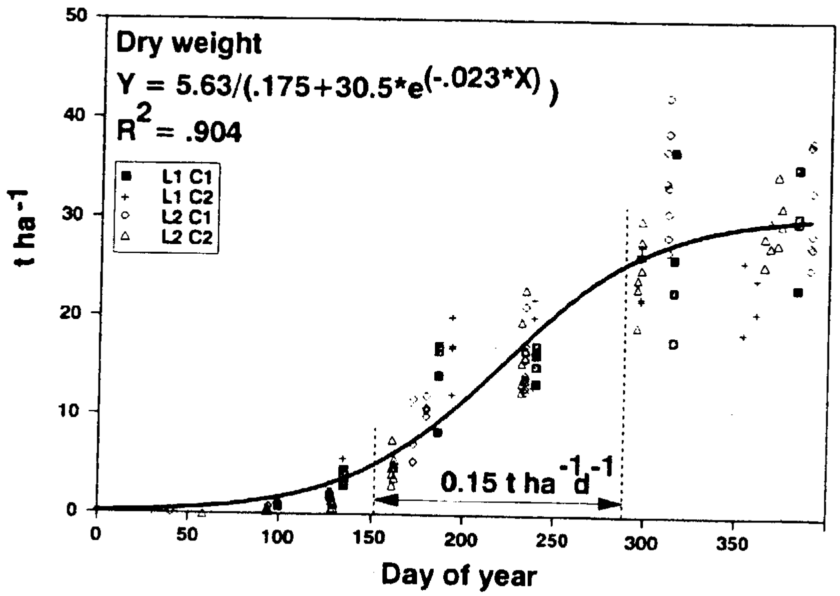

Fig. 1. Dry weight accumulation by sugarcane grown on organic soils of the Everglades Agricultural Area. (L1 = location 1, L2 = location 2, C1 = crop 1, C2 = crop 2).

Histosols of the EAA are underlaid by a hard limestone rock formation into which the local drainage/irrigation canal system is excavated. Therefore, the exchange phase of the organic soils tend to be dominated by Ca (Lucas, 1982). Calcium accumulation by sugarcane was described by a logistic model similar to the models derived for N, P, and K uptake (Fig. 5). One notable difference was the absence of a well defined stationary phase for crop Ca accumulation at crop maturity.

Magnesium was the final macro-nutrient for which uptake was modelled in our study (Fig. 6). As with the other macro-nutrients, Mg uptake was most rapid during the GGP, when 62% of total crop Mg accumulation occurred.

In this experiment, ratoon crops were evaluated for dry matter and nutrient removal from the field by crop harvest. An average fresh gross weight of 103 t millable sugarcane ha^{-1} was harvested. At harvest, 71% of the total dry matter accumulated was removed from the field as millable sugarcane (Table 2). The remaining 29% of plant dry matter was composed of leaves and tops which, commercially, would either be burned prior to harvest and remain in the field as ash or be cut from the stalk at crop harvest and remain in the field as intact plant tissue.

An average of 78 kg N ha^{-1} was removed from the field by crop harvest (Table 2). Nitrogen removal accounted for 55% of total crop N accumulation and was

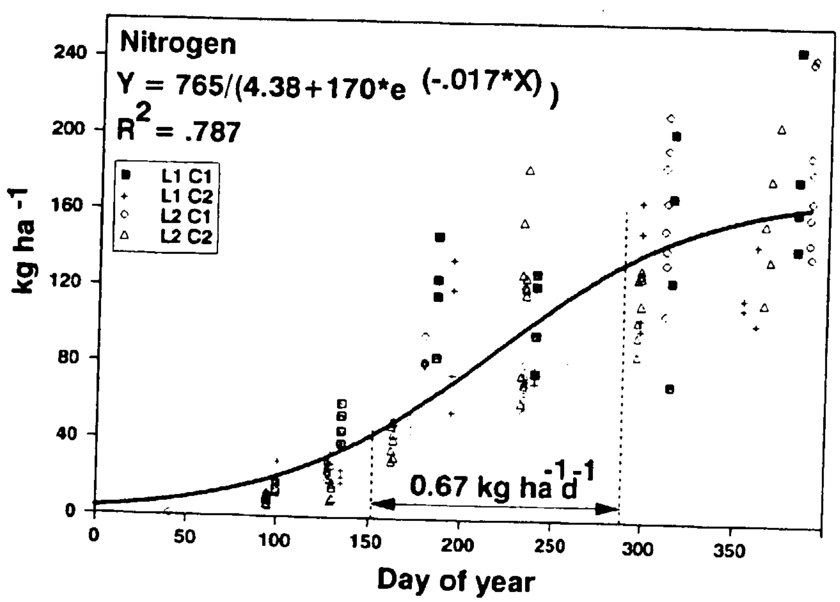

Fig. 2. Nitrogen accumulation by sugarcane grown on organic soils of the Everglades Agricultural Area. (L1 = location 1, L2 = location 2, C1 = crop 1, C2 = crop 2).

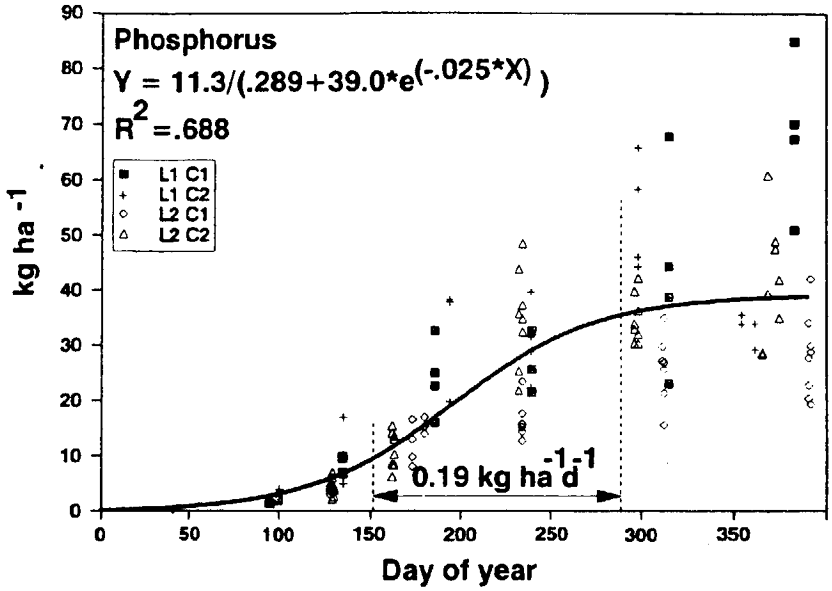

Fig. 3. Phosphorus accumulation by sugarcane grown on organic soils of the Everglades Agricultural Area. (L1 = location 1, L2 = location 2, C1 = crop 1, C2 = crop 2).

equivalent to 0.76 kg N t^{-1} millable sugarcane. This estimate is very similar to that determined by Golden and Ricaud (1963) of 0.72 kg N t^{-1} millable sugarcane harvested from mineral soils in Louisiana. Andreis (1975) evaluated the nutrient concentration of sugarcane as delivered to a commercial sugar mill and reported a higher average crop removal from organic soils of the EAA of 1.11 kg N t^{-1} millable sugarcane.

Phosphorus removed by crop harvest averaged 23 kg P ha^{-1} or 0.22 kg P t^{-1} millable sugarcane (Table 2). Andreis (1975) and Golden and Ricaud (1963) reported similar values for P removal by crop harvest of 0.16 and 0.18 kg P t^{-1} millable sugarcane, respectively. Crop P removal was equivalent to 63% of total crop accumulation and 179% of added fertilizer P. Apparently, fertilizer P was a minor contribution to the total soil pool of plant available P.

An average of 343 kg K ha^{-1} was removed from the field by crop harvest, accounting for 64% of total crop accumulation (Table 2). Potassium removed by crop harvest was equivalent to 201% of the K fertilizer applied. As was observed for P accumulation, fertilizer K appeared to be a minor contributor to the total supply of plant available K. These K removal data (3.33 kg K t^{-1} sugarcane) are inexplicably much higher than the 1.67 and 1.22 kg K t^{-1} presented previously by Andreis (1975) and Golden and Ricaud (1963), respectively.

Calcium and Mg removal by sugarcane harvest ac-

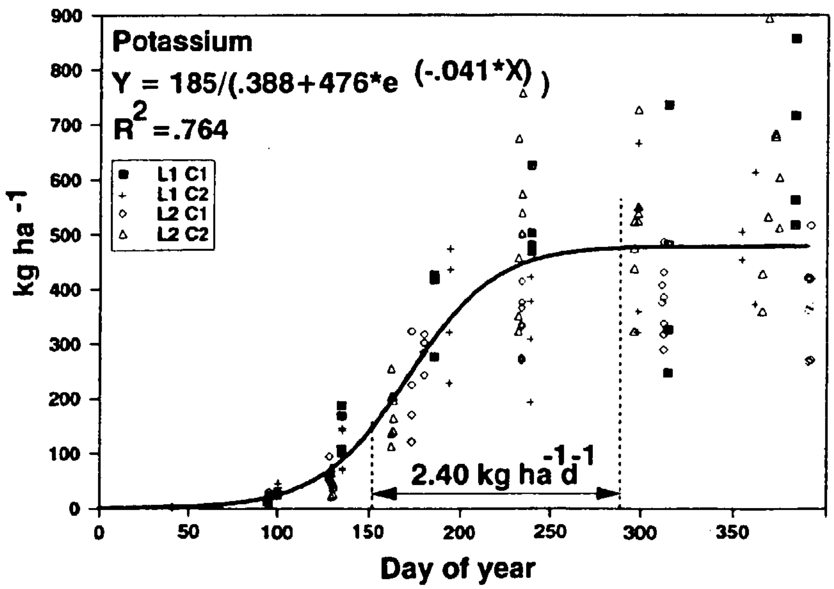

Fig. 4. Potassium accumulation by sugarcane grown on organic soils of the Everglades Agricultural Area. (L1 = location 1, L2 = location 2, C1 = crop 1, C2 = crop 2).

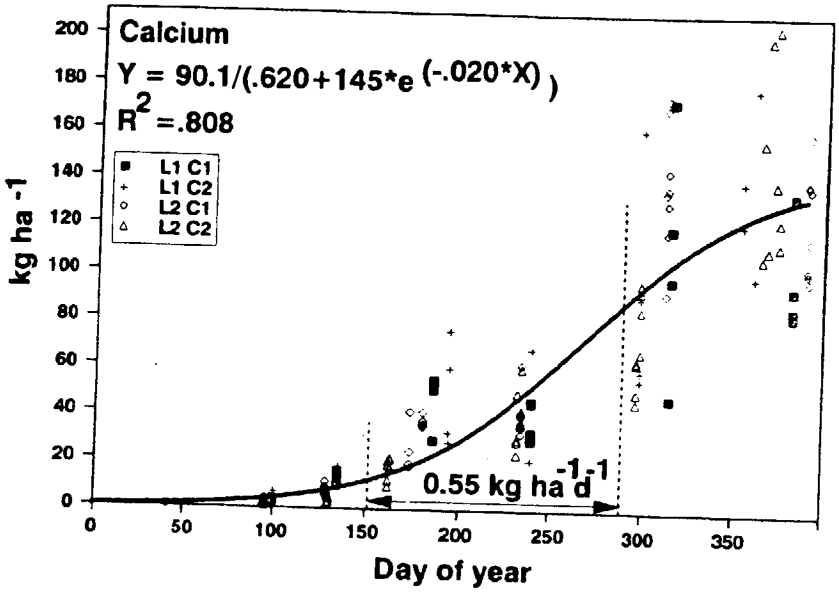

Fig. 5. Calcium accumulation by sugarcane grown on organic soils of the Everglades Agricultural Area. (L1 = location 1, L2 = location 2, C1 = crop 1, C2 = crop 2).

counted for 25% and 38%, respectively, of total crop accumulation (Table 2). Harvested Ca and Mg was equivalent to 0.34 and 0.25 kg t^{-1} millable sugarcane, respectively. These removal estimates are similar to the 0.41 kg Ca t^{-1} and 0.35 kg Mg t^{-1} reported by Andreis (1975) for sugarcane grown on organic soils in the EAA.

Analyses of a single random sample of raw sugar collected at a commercial Florida sugar mill in 1989 indicated 0.04, 0.01, 0.05, 0.06, and 0.004% N, P, K, Ca, and Mg, respectively. These raw sugar nutrient concentrations were similar to those presented by Honig (1953). Analyses of a single random sample of molasses indicated 0.86, 0.06, 6.00, 0.93, and 0.78% N, P, K, Ca, and Mg, respectively. These nutrient concentrations were within the range of values given for molasses by Meade and Chen (1977). In 1990, 170,000 ha of sugarcane were harvested in Florida which, in turn, produced 12.4 million t of sugarcane, 1.6 million t of raw sugar, and 0.5 million t of molasses (USDA, 1991). By assuming that the nutrient removal data presented previously were averages that represented the entire Florida sugarcane crop and by applying these averages to the state production statistics, the total quantity of nutrients harvested as millable sugarcane can be estimated (Table 3). The total quantity of nutrients exported from the EAA in raw sugar and molasses can similarly be estimated (Table 3). It was apparent that nearly all of the Ca and Mg and half of the K removed from the field by sugarcane harvest was removed from the EAA in exported products. On the other hand, only 12% of the P and 37% of the N harvested from the field as millable sugarcane was exported from the EAA.

Recent concerns regarding the impact of nutrient-rich drainage water from organic soils on the ecology of adjoining bodies of water and wetlands have generated a renewed emphasis on efficient management of native and applied nutrients. The sugarcane nutrient accumulation models and harvest removal data presented in this study

Table 3. Calculated total nutrient content of harvested sugarcane and estimated nutrient export from the Everglades Agricultural Area in raw sugar and molasses.†

Nutrient	Harvested millable sugarcane	Exported raw sugar	Exported molasses	Exported percent of harvested
	t			%
N	13 260	640	4 300	37
P	3 910	160	300	12
K	58 310	800	30 000	53
Ca	5 950	960	4 650	94
Mg	4 420	64	3 900	90

†Based on USDA, 1991.

Table 2. Aerial dry matter (DM) and nutrient accumulation and removal from a sugarcane field by ratoon-crop harvest.†

Parameter	Total crop accumulation	Total removed from field by crop harvest	Percent of crop accumulation removed	Percent of fertilizer addition removed
	kg ha^{-1}	kg ha^{-1}		
DM	27 056 (1301)‡	19 395 (2312)	71 (7)	—
N	142 (12)	78 (11)	55 (8)	—
P	38 (3)	23 (3)	63 (9)	179 (28)
K	554 (43)	343 (50)	64 (10)	201 (30)
Ca	142 (11)	35 (4)	25 (3)	—
Mg	68 (4)	26 (3)	38 (5)	—

†Mean harvested-crop fresh gross weight = 103 t ha^{-1}.
‡Values in parentheses are standard error of the mean, $n = 12$.

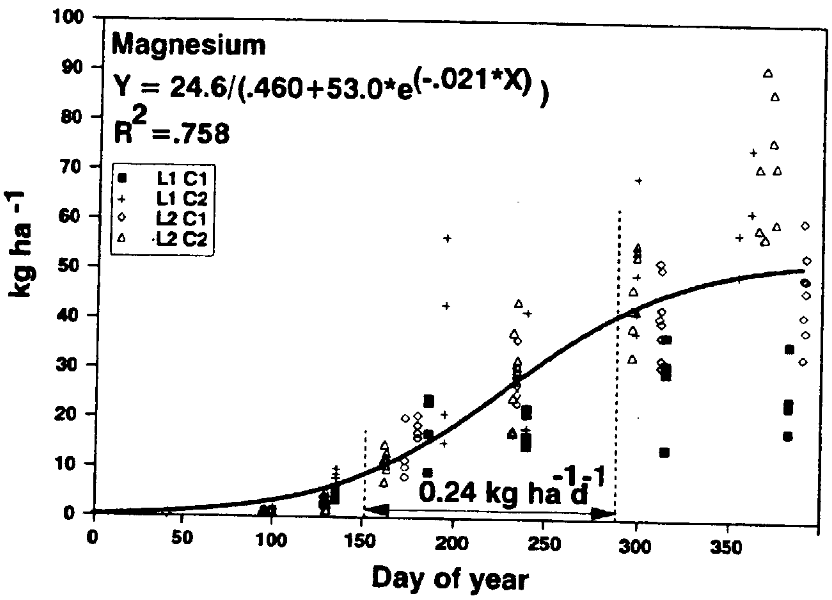

Fig. 6. Magnesium accumulation by sugarcane grown on organic soils of the Everglades Agricultural Area. (L1 = location 1, L2 = location 2, C1 = crop 1, C2 = crop 2).

may be used in refining the recommended quantity and timing of fertilizer applications. These data may also be used in developing timing strategies for the potential use of nutrient-rich water as a fertigation source for sugarcane. Nutrient accumulation patterns should be incorporated into any management plan designed to minimize the impact of sugarcane production on the surrounding environment.

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