Soil resilience and management of former sugarcane (*Saccharum officinarum* L.) lands on the Naparima Peneplain, Trinidad and Tobago

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The lands of the Naparima Peneplain, Trinidad and Tobago, are an invaluable resource with multiple land use characteristics including agricultural diversification. Sections are classified as Class V soils, non-resilient with minimum recovery over the medium term, and as Class IV soils, slightly resilient with improvements in medium term resulting in significant land management and land use changes. These lands were under sugarcane cultivation for centuries, from the colonial era until the closure of the sugar factory in 2003. Since then, as in so many other Caribbean territories, the land has been ear-marked for agricultural diversification and made available to small farmers for the production of commodities for the domestic market. Land use changes in the post-sugarcane era have resulted in approximately 14,000 hectares becoming available for possible agricultural diversification. However, the positive impact on domestic food supply that was anticipated has not materialized.

A land resource study was conducted in 2012–2014 in the La Gloria and Cedar Hill sections of Caroni (1975) Ltd lands on the Naparima Peneplain, to determine the effect of long-term sugarcane (*Saccharum officinarum* L.) cultivation on land degradation and soil resilience by comparison with data from historical records and to make recommendations on the way forward. Assessment of land use, chemical and physical soil properties, and extent of soil erosion, comprised the study.

The most severe land management factor was identified as chronic and widespread soil erosion, especially in Cedar Hill, with additional problems of subsoil exposure, soil slumping and movement. Soil erosion studies (Universal Soil Loss Equation (USLE)) indicate estimates of 35–74 t/ha affecting 75% of the lands. Historical records on soil physical indices such as bulk density, clay percentage in the profile and available water, revealed that these parameters were stable over the period 1977–2014. However, chemical indices, inclusive of organic carbon, nitrogen and pH, reflect significant decline correlated with reduced soil fertility and land abandonment. While identifying stable soil resilience indices is valuable, the immediate problem is the correction of soil erosion, which results in considerable land abandonment. Therefore, it is recommended that the land be restored to an acceptable level of soil fertility, specifically with respect to its organic matter content, and that infrastructural adjustments be made to stop or greatly minimize soil erosion so that these lands could be used to contribute to national food security as envisaged.

Keywords: Naparima Peneplain, soil resilience, land degradation, sugarcane, physical and chemical indices

Caroni (1975) Limited, a sugar-based agro-industrial state company in Trinidad and Tobago, terminated its core business of sugarcane (*Saccharum officinarum* L.) cultivation for sugar production in 2003, releasing approximately 31,000 hectares of lands for alternative land use, including agricultural diversification (Persad 2004). Establishment of viable production farms on Caroni (1975) Limited extensive land holdings became a key policy initiative of the Government of Trinidad and Tobago, with the stated objectives of enhancement of domestic food production, generation of agricultural activity in rural communities, sustainable management of strategic land resources and the enhancement of national food security. Agriculture in Trinidad and Tobago is a declining sector contributing less than 0.5% of GDP (2014), and characterized by an aging farm population, low productivity, low levels of technological inputs, inadequate

infrastructure and an over-reliance on the use of agricultural chemicals. Additionally, on an annual basis, Trinidad and Tobago imports food, especially staples, dairy and meat products to the value of four billion Trinidad and Tobago dollars.

The Naparima Peneplain is a distinct physiographic region of South Trinidad with an estimated area of 500 km^2. Weil and Brady (2017) define a peneplain as "a once high, rugged area that has been reduced by erosion to a lower, gently rolling surface, resembling a plain." The sedimentary geologic material that comprises the Naparima Peneplain was deposited in the Pliocene to Upper Eocene epoch (3 to 36 million years ago), and is dominated by calcareous shale and marls (Ahmad 2011). The topography is heavily dissected and undulating with a maximum elevation of 20-30 m. The major rivers are the Cipero and Poole that flow west and east, respectively. The climate is classified as tropical maritime with two distinct seasons, a dry season from December to April and a wet season from May to November (Ramnarine and Dipchansingh 2015). Rainfall is extremely variable with the 30-year (1980-2010) average computed as 1646 mm with 20.3% occurring in the dry season and 79.7% in the wet season. The average maximum and minimum temperatures are 31.3 °C and 22.7 °C, respectively, with a relative humidity in the wet season of 85-89%. The soil moisture regime is Udic while the soil temperature regime is Isohyperthermic (Smith 1983).

The principal soil order is the Vertisols and the major soil series and USDA taxonomic classification are as follows: Talparo (44.7%) – very-fine, mixed, acid, Aquentic Chromuderts; Tarouba (15.6%) – very-fine, montmorillonitic, Aquentic Chromuderts; Princes Town (14.3%) – very fine, montmorillonitic, non-acid, Aquentic Chromuderts; Debe (8.6%) – very fine, mixed, acid, Entic Pelluderts; La Fortune (9.0%) – very fine, mixed, non-acid, Entic Pelluderts, and Sevilla (7.8%) – very fine, montmorillonitic, non-acid, Aquentic Chromuderts (Smith, 1983).

Field surveys and analyses of land distribution initiatives of Caroni (1975) holdings by Persad et al. (2009) indicated that less than 5% of lands allocated to agriculture were cultivated. The "two-acre farms" (.81 ha) and large commercial farms were disorganized despite considerable expenditure on infrastructure by state agencies. Farmers who attempted to cultivate lands were challenged by a range of soil technical and agronomic constraints including, *inter alia*, inadequate land clearing, low soil fertility, eroded soils, rudimentary access roads, poor drainage and a complete absence of irrigation facilities. A major limitation was the lack of application of soil management technology for utilizing heavy clay soils of former sugarcane lands, especially southern Vertisols. The status quo remained intact in 2014.

Soil resilience, as a major pedological factor, has received minimal research attention in the Caribbean. However, soil resilience is a significant land quality factor influencing productivity and utilization of former sugarcane lands for agriculture. Soil resilience concepts have evolved from ecological resilience (Blanco and Lal 2008) and the development of soil resilience indices and classification are fundamental to sustainable land management for agricultural diversification. Therefore, agricultural land-use planning incorporating soil resilience targets and specific management interventions, is critical since it reduces land degradation and maximizes land productivity (Seybold, Herrick, and Brejda 1999).

Among the many definitions of soil resilience, the most appropriate is that of Blanco and Lal (2008) who presented a rationale of the inherent and intrinsic ability of lands to recover from degradative processes, a characteristic of long-term monoculture. Inherent factors include geomorphology, climate and drainage; while intrinsic factors

include physical, chemical and biological properties.

The objective of this study was to compare current soil physical and chemical properties to data from historical records, and evaluate current land use on two section of lands on the Naparima Peneplain: La Gloria and Cedar Hill.

Method

The land resource investigation on the Naparima Peneplain in 2012-2014 was comprised of the following 5 phases:

Phase 1:
A reconnaissance survey supplemented by desktop investigations to identify major landscape components of geomorphology, drainage, soil morphology and land use.

- The dataset included current and historical aerial photographs, topographic maps and soil/land use reports.

Phase 2:
A grid survey of La Gloria (2800 ha) and Cedar Hill (1600 ha) with inspections of 45 soil profiles in La Gloria and 26 in Cedar Hill.

- Investigations were confined to profile description and included profile depth, marl exposure, texture, infiltration, degree of soil slumping, soil movement and land use.

Phase 3:
Laboratory analyses on samples at the Analytical Laboratory, Research Division.

- Analyses included soil physical properties such as bulk density and particle size distribution (Landon 1984) together with soil chemical properties including pH, OC (Nelson and Sommers 1996), N, P, K, Ca, and Mg (Bremner 1996).

Phase 4:
Determination of potential soil indices (Lal 1994, 1997; Seybold et al. 1999).

- Historical published data from the Imperial College of Tropical Agriculture (ICTA), Tate and Lyle Sugar Company, Caroni Research Station and the Ministry of Agriculture, Trinidad and Tobago, were used as references for the comparative analytical study.

Phase 5:
Statistical analysis of data using SPSS (IBM Corp. Released 2017. IBM SPSS Statistics for Windows, Version 25.0. Armonk, NY).

- Data were tested for normality using the Shapiro-Wilk test and evaluated by analysis of variance (ANOVA) using $p < 0.05$ value to determine significant differences between means.

Results and discussion

Land use on the Naparima Peneplain

At the closure of the sugar factory in 2003, approximately 14,000 hectares of state and private sugarcane lands were under cultivation with smaller land areas allocated to vegetable, livestock and citrus enterprises. However, from 1900, agricultural reports indicated severe land degradation and soil fertility depletion on the Naparima Peneplain. Attempts at agricultural diversification were confined to the poorer degraded lands at La Gloria, Picton, Craignish, and Williamsville, which resulted in overall project failure and minimum technical information to guide diversification. Land use on the Naparima Peneplain is presented in Table 1.

Soil chemical indices

Five key soil chemical parameters were selected from the analytical data set for further evaluation to determine potential resilience indices. The actual levels in 2014, while important as a soil fertility reference, were compared to soil data for 1969 and 1999 (Table 2). Stable resilience indices were a function of soil series rather than time. In 474/L, Princes Town Series, stable chemical indices were nitrogen, potassium and calcium. In 278/L, Tarouba Series, stable indices were pH, Ca, K, while in 177 Talparo series, stable indices were OC, pH and Ca.

Overall, Ca and K levels were stable over the forty-five year period. However, Ca and K levels were highly correlated with marl levels (r =0.76) which were related to degree of soil erosion and soil movement. Organic carbon, which has been proposed as a reference index (Lal 1997), was stable only in the Talparo series.

Table 1: Change in agriculture land use on the Naparima Peneplain from 2000 to 2015

Land Use Type	Land Use Area (ha)		% Change
	Year 2000	Year 2015	
Sugarcane (Estate)	8470	0	–100.0
Sugarcane (Private)	5750	350	–93.9
Tree Crops (Citrus, Cocoa)	2850	2850	0.0
Vegetable/ Food Crops	3500	4200	+20.0
Livestock	3750	3750	0.0
Forest	2200	2200	0.0
TOTAL	26120	13350	–48.9

Table 2: Changes in key soil chemical indices by soil series (1969-2014)

Soil Series	Indices	1969	1999	2014	P-value
474/L Princes Town	N (g/kg)	2.16	1.87	1.89	NS
	OC (g/kg)	18.3	18	10.2	$p<0.05$
	pH	7.36	7.43	7.93	$p<0.05$
	Ca ($cmol_c/kg$)	23.6	23.5	27.3	NS
	K ($cmol_c/kg$)	0.41	0.39	0.34	NS
278/L Tarouba	N (g/kg)	2.22	1.8	1.4	$p<0.05$
	OC (g/kg)	18.0	12.6	9.9	$p<0.01$
	pH	6.91	7.3	7.18	NS
	Ca ($cmol_c/kg$)	22.5	23.5	19.36	NS
	K ($cmol_c/kg$)	0.34	0.39	0.32	NS
177 Talparo	N (g/kg)	2.43	2.06	1.76	$p<0.05$
	OC (g/kg)	10.4	10.5	9.2	NS
	pH	5.01	4.63	4.53	NS
	Ca ($cmol_c/kg$)	3.6	3.1	2.9	$p<0.05$
	K ($cmol_c/kg$)	0.36	0.38	0.37	NS

NS – Not significant at the P = 0.05 level

Table 3: Soil physical indices by soil series, 1977[1]-2014

Index	474/L Princes Town		278/L Tarouba		177 Talparo		P-value
	2014	1977	2014	1977	2014	1977	
Bulk density, 0-30 cm (Mg/m^3)	1.27	1.22	1.23	1.60	1.21	1.08	NS
Clay, 0-30 cm (%)	74	68	82	74	74	76	NS
Available water ($mm\ m^{-1}$)	256	265	213	217	182	218	NS

[1] *Source*: Data from Georges (1977)
NS – Not significant at the P = 0.05 level

Table 4: Soil erosion on the Naparima Peneplain (USLE) as found in the current study

Location	Soil Series	Soil Loss (t/ha)	% of Lands Affected
La Gloria	474/L Princes Town	14.8	35.3
	278/L Tarouba	23.3	32.1
	177 Talparo	17.9	18.6
Cedar Hill	474/L Princes Town	34.6	76.3
	278/L Tarouba	32.8	73.3
	177 Talparo	22.8	52.1

Soil physical indices

Selected key soil physical indices such as bulk density, clay percentage and available water are presented in Table 3. Comparisons were made using data of Georges (1976) and that obtained from the current study. The analysis indicated that soil physical properties were relatively stable over the period 1977–2014 and can be used for development and modelling of soil resilience indices over the three major soil series. Bulk density, clay percentage and available water reflected no significant differences from published data.

Soil erosion

The effects of soil erosion on the Naparima Peneplain were documented as early as 1930 with a consequent exposure of infertile subsoil marls. The current study showed that extended acreages of sugarcane lands in La Gloria, Craignish, Hindustan, Moruga, and Brothers Road, Tableland were abandoned due to soil fertility depletion and land slippage. Additionally, land degradation was a principal problem in the Petite Morne and Cedar Hill sections. The current study also found that soil erosion was extremely severe in Cedar Hill especially where lands were allocated for two-acre farms. Also, erosion was accelerated by down-slope tillage, soil slumping and movement, and gully development. Findings of this current study indicate that the extent of subsoil exposure was acute and present severe limitations to soil management. Soil erosion and its consequences rather than soil physical and chemical properties have the most important impact on soil resilience and land management. The deleterious effects of soil erosion are indicated in Table 4. Benitez et al. (2004) identified that the amplitude (time for lands to recover from disturbance) is a function of physical, chemical, biological, and hydrological processes.

Soil and land management

Agricultural development of the extensive areas of Vertisols on the Naparima Peneplain, South Trinidad (underutilized and abandoned because of cessation of sugarcane cultivation) is dependent on a systematic appraisal of land quality and utilization characteristics. Soil resilience indices developed from evaluation of pedology and agro-ecological assessments (Blanco and Lal 2008) form a theoretical basis for sustainable management.

Sugarcane cultivation on the Naparima Peneplain began in 1787 under Spanish rule. Subsequently, the country was captured 10 years later by the British (Lovell 2012). Sugarcane production was historically interwoven in the socio-economic environment of the Naparima Peneplain through the provision of employment, infrastructure, and commerce over approximately 200 years. Land evaluation research to inform land resource allocation and adaptation strategies has been extremely limited. The result has been inadequate exploitation of a potentially valuable and needed resource because the necessary interventions have not been made. Therefore, what is needed going forward, is that the land be restored to an acceptable level of soil fertility, specifically with respect to its organic matter content, given that most important mineral components remained stable over the forty-five-year period of the study. It is recommended further that infrastructural adjustments be made to stop or greatly minimize soil erosion so that these lands could be used to contribute to national food security as envisaged.

Conclusion

Analysis of key soil properties and land use on the Naparima Peneplain reflects that lands are extremely fragile and exhibit severe land degradation. The key issues identified in this study were declining soil fertility, poor land use practices and chronic and widespread soil erosion. Lands under Princes Town and Tarouba clays are classified as Class V, non-resilient with minimum recovery over the medium term. Lands under Talparo clays are classified as Class IV, slightly resilient with improvements in medium term resulting in significant land management and land use changes. Accordingly, the key issues identified in this study can be addressed to restore fertility and beneficial land use.

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References

Ahmad, N. 2011. *Soils of the Caribbean.* Kingston, Jamaica: Ian Randle Publishers.

Benitez, E., R. Melgar, and R. Nogales. 2004. "Estimating Soil Resilience to a Toxic Organic Waste by Measuring Enzyme Activities." *Soil Biology and Biochemistry* **36 (10):** 1615-1623.

Blanco, H., and R. Lal. 2008. *Principles of Soil Conservation and Management*. New York: Springer.

Bremner, J.M. 1996. 'Nitrogen-Total." In *Methods of Soil Analysis: Chemical Methods*, Part 3, edited by D. L. Sparks, 1085-1122. Madison, WI: Soil Science Society of America, Inc.

Georges, J.E.W. 1976. *Survey of Soil Physical Properties of Caroni (1975) Ltd*. Caroni Research Station Annual Report, 1976-77: Carapichaima, Trinidad and Tobago.

Lal, R. 1994. "Sustainable Land Use Systems and Soil Resilience." In *Soil Resilience and Sustainable Land Use*, edited by D.J. Greenland and I. Szabolcs, 41-67. United

Kingdom: CAB International Publishers.

Lal, R. 1997. "Degradation and Resilience of Soils." *Philosophical Transactions of the Royal Society B: Biological Sciences* **352 (1356): 997–1010**. doi:10.1098/rstb.1997.0078

Landon, J.R. 1984. *Booker Tropical Soil Manual: A Handbook for Soil Survey and Agricultural Land Evaluation in the Tropics and Subtropics.* New York: Longman.

Lovell, Francis. 2012. "Transformations in the Trinidadian Sugar Industry: Caroni, State Intervention and the Sugar Sub-Sector in Trinidad." Ph.D. Thesis. The University of the West Indies, St. Augustine, Trinidad and Tobago.

Nelson, D.W., and L.E. Sommers. 1996. "Total Carbon, Organic Carbon, and Organic Matter." In *Methods of Soil Analysis: Chemical Methods*, Part 3, edited by D. L. Sparks, 961-1010. Madison, WI: Soil Science Society of America, Inc.

Persad, S. 2004. "Land Use Planning for Agricultural Diversification of Sugarcane Estates in Trinidad and Tobago." *Proceedings of the 40th Annual Caribbean Food Crops Society (CFCS) Meeting, July 19-23, 2004.* St. John, US Virgin Islands.

Persad. S., I. Rampersad, and R. Roop. 2009. "Food Crop Production and Land Management for Caroni (1975) Limited '2 Acre Farms' in Trinidad and Tobago." *Proceedings of the 45th Annual Caribbean Food Crops Society (CFCS) Meeting*: *July 12-17, 2009*. St. Kitts and Nevis.

Ramnarine, R., and D. Dipchansingh. 2015. "Agroforestry Systems and Practices in the Caribbean." In *Sustainable Food Production Practices in the Caribbean*, volume 2, edited by W.G. Ganpat and W.P. Isaac, 353-379. Kingston, Jamaica: Ian Randle Publishers.

Seybold, C.A., J.E. Herrick, and J.J. Brejda. 1999. "Soil Resilience: A Fundamental Component of Soil Quality." *Soil Science* **164 (4)**: 224-234.

Smith, G.D. 1983. *Soil and Land-Use Surveys*. No. 27. Published on behalf of the Faculty of Agriculture, The University of the West Indies by August Publications, Farnham, England.

Weil, R.R. and N.C. Brady. 2017. *The Nature and Properties of Soil.* 15th edition. London, UK: Pearson Education Limited.