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Heterogeneity of Soil pH Across Soils Grown for Sugarcane in the Western Viti Levu, Fiji

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Abstract: ***Soil pH is a key characteristic to be considered in sugarcane agriculture as this form the fundamental basis for the yield output. This study analyzed 772 fallow field soil samples collected from the western division of Fiji Islands sugarcane belt, with samples taken at 0 - 20cm depth using a 1: 5 soil/water ratio for pH determination. Field extension officers from the Fiji Sugar Corporation (FSC) classified the soil types during sampling, with similar soil types subsequently grouped for analysis. The study encompassed 11 distinct soil types, revealed predominantly acidic conditions: 9% strongly acidic, 48% acidic, and 43% slightly acidic. pH values demonstrated considerable variation, ranging from 3.5 to 7.7, with an average of 5.5. Among the 25 sectors studied, Lomawai recorded the lowest pH values while Qeleloa showed the highest, indicating significant spatial heterogeneity in soil acidity across the region. Statistical analysis revealed significant differences in pH levels between soil types ($p < 0.001$), suggesting that soil type is a crucial factor in determining soil pH characteristics. Nigrescent soil emerged as the predominant soil type across the sugarcane belt, exhibiting moderate pH variability with a standard deviation of 0.59. In contrast, sandy soils were the least common but showed remarkable pH stability with a standard deviation of just 0.21. Clay soils demonstrated the highest pH variability (standard deviation 0.78), suggesting the need for more targeted management approaches in these areas. The findings indicate that soil amendments or crop rotation practices may be necessary to achieve the targeted optimal pH of 6.5 for sugarcane cultivation in these regions. The findings of this comprehensive pH analysis will enable agricultural stakeholders to develop nuanced, soil - type - specific management strategies, ultimately improving soil health, lime amendment efficiency, and crop productivity within Fiji's sugarcane industry.***

Keywords: sector, soil pH, soil type, acidic, soil samples

1. Introduction

Soils play a critical role in meeting human food needs. Their conservation and wise use are essential today and will be even more critical in the future as population pressures increase (Brady, 1984). In simple term, soil is “the dirt” that is present on the surface of the earth (Jenny, 1941) but it is defined by Patel, et al (2014) as a naturally occurring porous medium that supports the growth of plant roots by retaining air, heat, water and nutrients; and provides mechanical support to the plant and by authors Brady and Weil as the uppermost layer of the Earth’s surface, composed of minerals, organic matter, gases, liquids, and a myriad of living organisms. It forms through the weathering of rocks and the decay of organic material, developing over long periods. Soil serves as a fundamental resource, supporting plant life by providing essential nutrients, water, and a medium for root growth. It also plays critical roles in carbon and nitrogen cycles, water filtration, and ecosystem health (Brady and Weil, 2002)

Fiji enjoys a mild tropical climate with heavy rain under prevailing conditions, although there are definite “hot and wet” (Oct - Apr) and “cool and dry” (May - Sept) seasons. There is a difference between the windward (wet zone) and leeward (dry zone) coasts of the larger islands. Average annual rainfalls for the wet zone range from 2800 mm to 3600 mm and for the dry zone from 1300 mm to 1600 mm. Mean temperatures range between 23°C - 27°C with humidity of 75% - 88% (Prasad, 2006).

Depleting soil health and crop productivity in the sugarcane cultivating areas of Fiji is a serious concern. From 1996 to 2022, statistical analysis reveals a significant decline in sugarcane land area from approximately 74, 000 hectares to 35, 000 hectares—a 47% reduction. Correspondingly, sugar production decreased from 4.3 million tonnes in 1996 to approximately 1.6 million tonnes in 2022, resulting in a decline in cane productivity from 59 to 47 tons per hectare over 26 years. (SRIF annual reports, 1996, 2020 - 2022).

Due to the increasing cost of cultivation, harvesting, transportation and the non - renewal of land leases and the decreasing profits received from sugarcane production, have all led to the loss of farmer faith in the industry (Dean, 2022).

Classification of soil is a powerful tool to utilize our national soil resource purposefully and scientifically (Mishra, 2016). Fiji can be classified as diverse in terms of geology, relief, climate and vegetation that yield a variety of soil groups and soil types. One of the outstanding physiological characteristics of the soil solution is its reaction – whether it is acidic, alkaline or neutral (Brady, 1984).

The Indian council for agricultural research (ICAR) has divided Indian soils into 8 major groups. They are; alluvial, black soil, red soil, laterite soil, desert soil, mountain soil, saline and alkaline soil and peaty soil (Balasubramanian, 2017). In contrast, Fijian soils are categorized into 11 major groups. They are; alluvial, bila soils, clay soils, gley soils, humic latosols, latosols, podzolic, red soils, saline, sandy and talasiga soils.

The relationship between soil pH and soil type is crucial in understanding the suitability of soils for sugarcane cultivation. A study by author Weerasinghe (Weerasinghe et al., 2020) found significant difference in mean Ph between 2 soil types; low humic gley and reddish - brown earth, pH values ranging from 4.4 to 9.3. Another study by author Megersa (Megersa et al., 2019) have shown that vertisols and luvisols have distinct characteristics that can influence pH levels. Another author (Zhao et al.) has investigated how pH levels vary across different soil depths and types., and that pH can differ significantly depending on the soil layer, indicating a strong relationship between soil type and pH levels.

The purpose of this paper is to provide information on the different Fijian soil types and the soil pH values associated with each type, whereby descriptive statistical analysis was used to analyze the soil samples datasets.

2. Materials and Methods

Study area – the study area is agriculture land of sugarcane growers across the sugarcane belt areas from Sigatoka to Rakiraki. This is the western side of Viti Levu, Fiji Islands. Fiji lies in the heart of the Pacific Ocean midway between the Equator and the South Pole, and between longitudes 175° east and 178° west and latitudes 15° and 22° south. There are two major islands - Viti Levu and Vanua. (About Fiji - History, Government and Economy, 2022). The study was carried out on the island of Viti Levu.

Soil sampling procedure – 10 core soil samples were systematically collected from a 0 - 20 cm depth using a zig - zag sampling pattern. These core samples were thoroughly mixed to create a single composite sample representative of the entire field. (Soil Sampling Factsheet No.16). The samples were collected by Fiji Sugar Corporation (FSC) extension team and provided to the Sugar Research Institute of Fiji (SRIF) laboratory. Samples were assigned a lab number and labelled as 1, 2, 3 respectively. In the lab, any sort of external materials, e. g. grass, roots etc. were removed, air - dried on aluminum drying trays, sieved using a 2mm screen and stored in properly labeled plastic bags for analysis. A total of 500 samples were taken for the correlation study. Figure 3 indicates the total number of samples received.

Soil analysis procedure – soil pH in water was determined for all samples in a ratio of 1: 5 soil to water suspension (4g soil/20ml water), as per procedure "determination of soil pH in water" following the "SRIF analytical laboratory method and standard operating procedure". Samples were shaken on an end - to - end shaker for one (1) hour and later pH readings were recorded using a 867 pH Module calibrated pH meter. Results were reported to one decimal place.

Tools and techniques –A statistical analysis was made of the soil samples measured pH data, whereby the mean, minimum, maximum, standard deviation (SD) and coefficient of variance (CV) was calculated. The soil pH data was analyzed using a one - way ANOVA to determine if there are significant differences in pH levels between the soil types.

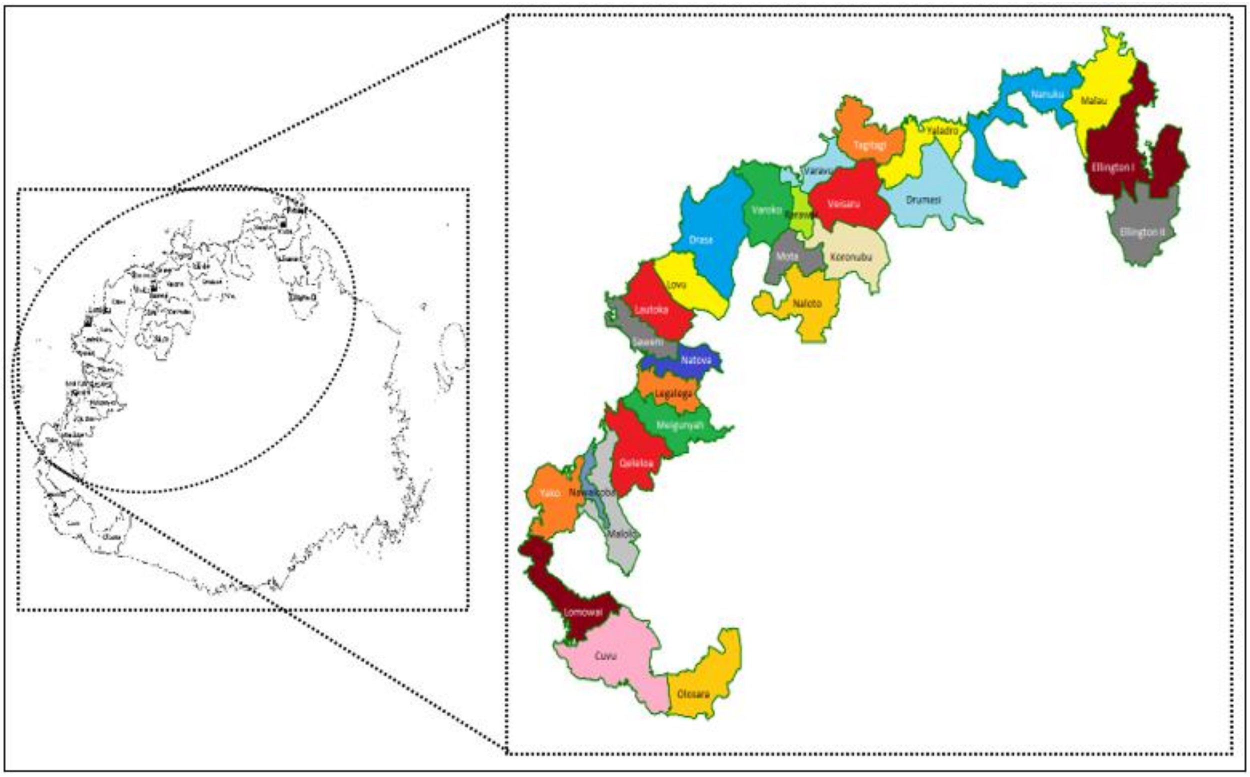

Figure 1: Sector map of the study site, Fiji Islands.

3. Results and Discussion

This study analyzed 11 major soil types in Fiji, examining their pH levels across 772 samples. One - way Analysis of Variance (ANOVA) was employed to analyze the soil sample data, calculating mean, minimum, maximum, standard deviation (SD), and coefficient of variance (CV) for the measured soil parameter.

Table 1: Major soil types in Fiji showing the mean, minimum, maximum, standard deviation (SD) and coefficient of variance (CV) values for soil pH

Major soil types in Fiji	N	Mean pH	Minimum pH	Maximum pH	Std Dev.	C. V.
Alluvial	94	5.2	3.9	6.2	0.5	0.3
Bila	54	5.3	4.3	6.3	0.5	0.2
Clay	77	6.0	4.2	7.7	0.8	0.6
Ferric Latosol	7	5.6	5.2	6.1	0.3	0.1

Gley	10	6.0	5.6	6.6	0.3	0.1
Humic Latosol	79	5.4	4.3	6.4	0.5	0.3
Nigrescent	353	5.6	3.5	7.1	0.6	0.4
Red	49	5.6	4.5	6.3	0.5	0.3
Saline	8	5.0	4.3	5.8	0.6	0.4
Sandy	5	5.9	5.6	6.1	0.2	0.0
Talasiga	36	5.1	3.9	6.3	0.5	0.3

A study by Makoro (2014) has indicated the impact of soil types on pH – different soil types have varying capacities to retain or release hydrogen ions, which directly affect the pH levels.

The soil pH analysis across Fiji reveals significant variations in both sampling intensity and pH characteristics among the eleven major soil types presently used in Fiji, thou the updated map derived from the Harmonized World Soil Database (HWSD) v2.0 identifies seven major soil types as classified by the Intergovernmental Panel on Climate Change (IPCC), (Maïdie et al., 2024).

Nigrescent soils emerged as the most extensively studied type, with 353 samples collected, providing a robust dataset for this particular soil category. In contrast, some soil types received minimal sampling attention, with Sandy soils having only 5 samples, Ferric Latosol 7 samples, and Saline soils 8 samples, which suggests a need for more comprehensive sampling of these soil types in future studies.

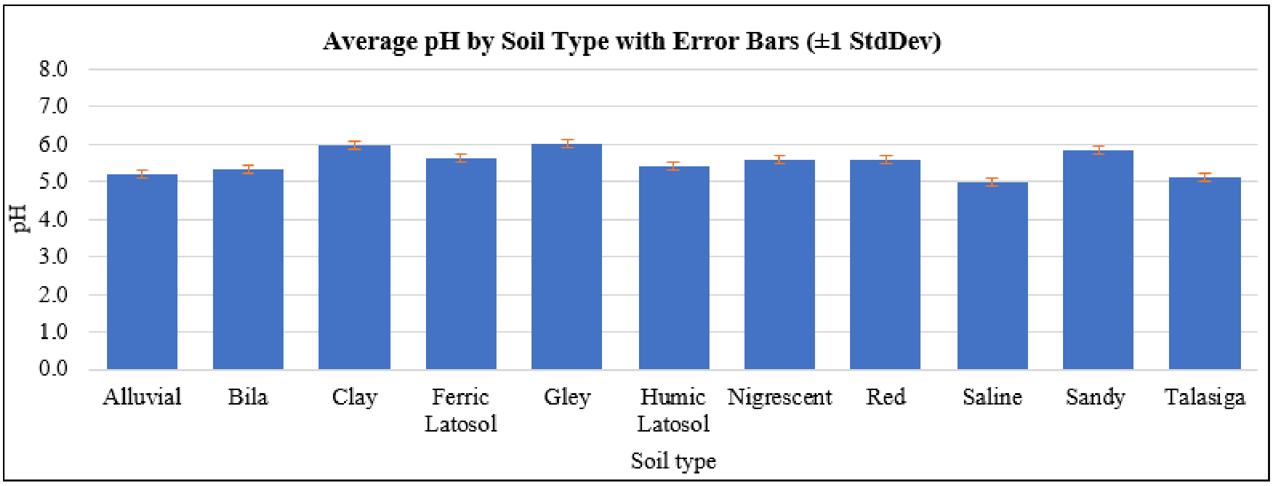

Figure 1: Average pH by Soil Type with Error Bars (±1 StdDev)

The pH measurements revealed interesting patterns across different soil types. Clay and Gley soils demonstrated the highest mean pH values at 6.0, indicating relatively neutral conditions compared to other soil types. Sandy soils followed closely with a mean pH of 5.9, though this finding was interpreted cautiously given the limited sample size.

On the more acidic end of the spectrum, Saline soils showed the lowest mean pH at 5.0, followed closely by Talasiga soils at 5.1 and Alluvial soils at 5.2. This predominance of acidic conditions across many soil types suggests that soil acidity management might be a crucial consideration for agricultural practices in Fiji. Bila soils, with a mean pH of 5.3, and Humic Latosol soils, at pH 5.4, represented intermediate acidic conditions.

The variation in pH values within each soil type revealed noteworthy patterns. Clay soils exhibited the highest variability, with a standard deviation of 0.78 and a coefficient of variance of 0.61, indicating substantial pH fluctuations within this soil type. The pH range in Clay soils spanned from 4.2 to 7.7, representing the widest range among all soil types. This high variability suggests that Clay soils might require more careful and site - specific management approaches with - in the sugarcane belt.
In contrast, Sandy soils demonstrated remarkable pH stability, with the lowest standard deviation of 0.21 and a coefficient of variance of just 0.04. The pH range in Sandy soils was notably narrow, from 5.6 to 6.1, suggesting more consistent and predictable soil conditions. Similarly, Gley soils showed relatively low variability with a coefficient of variance of 0.10, and Ferric Latosol followed with 0.11.

Nigrescent soils, despite having the largest sample size, showed moderate variability with a standard deviation of 0.59 and a coefficient of variance of 0.35. This soil type recorded the most extreme acidic reading at pH 3.5, while its maximum reached 7.1, indicating considerable pH variation across different locations.

The data suggests important implications for agricultural management in Fiji. The predominantly acidic nature of most soil types indicates that liming practices must be necessary for optimal crop production in many areas. The varying degrees of pH variability among soil types also suggest that different management approaches might be needed for different soil types, with some requiring more intensive monitoring and site - specific treatment strategies than others.

These findings also highlight several research gaps. The limited sampling of certain soil types, particularly Sandy, Saline, and Ferric Latosol soils, requires a need for more comprehensive sampling efforts to better understand these soil types. Additionally, the high variability observed in some soil types indicates that future research might benefit from more detailed spatial analysis to understand the factors driving these pH variations.

The statistical analysis revealed highly significant differences between soil types, as demonstrated by one - way Analysis of

Variance (ANOVA). The analysis yielded an exceptionally low p - value of 2.772e - 38, substantially smaller than the conventional significance threshold of 0.05. This extraordinarily small p - value indicates that the observed pH level differences between soil types are statistically unlikely to have occurred by chance.

The statistical significance is further supported by the F - statistic of 22.784, which measures the ratio of variance between soil types to variance within soil types. This relatively large F - statistic suggests that there is much more variation in pH levels between different soil types than within each soil type, providing strong evidence that soil type is a crucial factor in determining soil pH.

The extremely low p - value ($p < 0.001$) leads us to reject the null hypothesis that all soil types have the same mean pH level. In other words, we can conclude with very high confidence that there are genuine, systematic differences in pH levels among the different soil types in Fiji. This finding has important implications for agricultural management and soil treatment practices, as it suggests that different soil types may require different management approaches to optimize their pH levels.

These statistical results strongly support the earlier descriptive analysis, confirming that the observed differences in pH levels between soil types represent real, meaningful variations rather than random fluctuations. This understanding is crucial for agricultural planning and soil management strategies in Fiji, as it indicates that soil type should be a key consideration when developing pH management practices.

The statistical significance of these findings suggests that farmers, agricultural scientists, and land managers should take soil type into account when planning soil amendments or selecting crops, as the pH characteristics of different soil types are distinctly different and these differences are highly reliable rather than random variations.

The favorable pH range for good cane growth is 6 - 8 (Hunsigi 1993) but research trials conducted at SRIF (data not published online) have shown that a pH range of 5.5 – 6.5 is ideal.

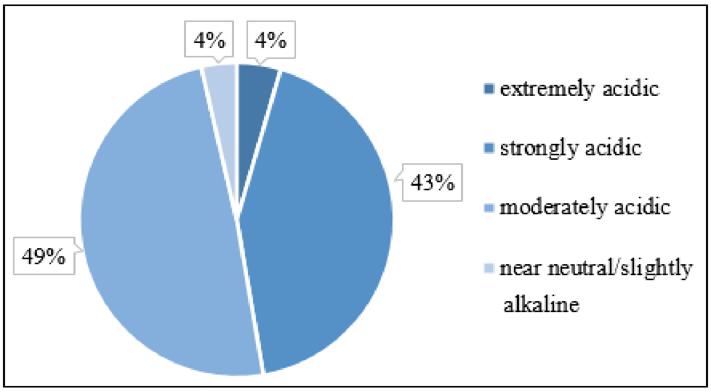

Figure 2: Soil pH classification, for the total soil samples, expressed as a percentage.

Within the Viti Levu sugarcane belt, mapped from Sigatoka to Rakiraki, each area under sugarcane has been divided into different sectors - an administrative subdivision of the sugarcane belt, each representing a distinct geographical area under specific management for sugarcane cultivation and monitoring. The sectors serve as a localized management unit for coordinating sugarcane farming activities.

The sugarcane belt of Viti Levu is divided into 28 sectors, which are further organized into 6 districts. These districts ultimately fall under two mill areas: Lautoka and Rarawai. Table 2 presents the organizational structure of these districts and their respective mill areas. The table shows the different sectors linked with the pH values recorded for the 772 soil samples.

Table 2: The minimum, maximum and average pH values, the standard deviation and the coefficient of variance of the soil samples studied.

District	Sector	N	Average pH	Minimum pH	Maximum pH	Std Dev	Var.
	Lautoka Mill						
	111 - Drasa	7	5.3	3.9	6.3	1.0	1.0
Lautoka	112 - Lovu	73	5.7	4.3	6.6	0.5	0.3
	113 - Lautoka	14	5.4	4.2	6.3	0.7	0.5
	114 - Saweni	12	5.1	4.3	6.3	0.6	0.4
	115 - Natova	31	5.2	4.0	6.1	0.6	0.3
Nadi	121 - Legalega	35	5.5	4.3	7.1	0.6	0.4
	123 - Meigunyah	41	5.6	4.6	6.9	0.5	0.3
	124 - Qeleloa	26	5.7	4.4	7.7	0.8	0.7
	125 - Yako	20	5.7	4.6	6.5	0.5	0.3
	126 - Malolo	25	5.5	4.3	7.0	0.7	0.4
	127 - Nawaicoba	39	5.6	4.3	6.8	0.6	0.3
	129 - Waqadra Estate	4	5.5	4.8	6.1	0.6	0.4

Sigatoka	131 - Lomawai	62	5.6	3.5	6.8	0.7	0.4
	132 - Cuvu	11	5.7	4.7	6.2	0.4	0.2
	133 - Olosara	10	5.6	4.6	6.2	0.6	0.3
	Rarawai Mill						
Rarawai	211 - Varoko	4	5.1	4.6	5.7	0.6	0.4
	212 - Mota	76	5.6	4.2	7.2	0.7	0.5
	213 - Koronubu	42	5.3	3.9	6.4	0.5	0.2
	214 - Rarawai	3	5.7	5.5	6.0	0.2	0.0
	217 - Naloto	51	5.6	4.2	7.4	0.7	0.5
Tavua	221 - Tagitagi	16	5.2	4.0	6.6	0.7	0.4
	222 - Drumasi	9	5.1	4.0	6.2	0.7	0.5
	223 - Yaladro	2	5.8	5.6	6.0	0.3	0.1
Penang	411 - Ellington 1	24	5.6	4.9	6.9	0.5	0.2
	412 - Malau	31	5.2	4.2	5.9	0.4	0.2
	413 - Nanuku	58	5.4	4.6	6.5	0.5	0.3
	414 - Ellington 2	46	5.7	4.3	6.6	0.6	0.3

The comprehensive soil pH analysis across the Viti Levu sugarcane belt reveals distinct patterns within its twenty - eight sectors, which are distributed between the Lautoka and Rarawai mill areas. The data collection provided valuable insights into soil acidity variations throughout the region.

In the Lautoka Mill area, the Lautoka district's five sectors displayed varying degrees of soil acidity, with Saweni recording the most acidic conditions averaging pH 5.1. The neighboring Lovu sector, with its substantial sample size of 73 measurements, maintained a more moderate average of pH 5.7, suggesting better soil conditions for sugarcane cultivation. The Nadi district demonstrated remarkable consistency across its seven sectors, with average pH values clustering between 5.5 and 5.7, though the Qeleloa sector notably recorded the study's highest individual pH measurement of 7.7.

Within the Rarawai Mill area, the soil conditions showed interesting variations across its districts. The Rarawai district's sectors presented a range of pH values, with the Mota sector's extensive sampling of 76 measurements revealing an average pH of 5.6. The Penang district's four sectors displayed a narrower pH range, with averages between 5.2 and 5.7, suggesting more uniform soil conditions in this area. The Tavua district generally exhibited more acidic conditions, though the limited sampling in sectors like Yaladro (with only two measurements) necessitates cautious interpretation of these results.

Standard deviation values across the sectors provided insights into soil pH consistency, ranging from highly uniform conditions in the Rarawai sector (standard deviation 0.2) to more variable conditions in the Drasa sector (standard deviation 1.0). These variations suggest differing levels of soil heterogeneity across the sugarcane belt, which may influence agricultural management practices and productivity outcomes.

Figure 4 shows the percentage of the different soil types recorded of the 500 soils taken for the study. The top 3 soil types on record were nigrescent with 36%, alluvial with 21% followed by clay at 15%. The least soil types to be found from the study were ferric latosol and sandy with 0.6% and 0.4% respectively. The median value calculated was 3.6% and this corresponded to the red soil type.

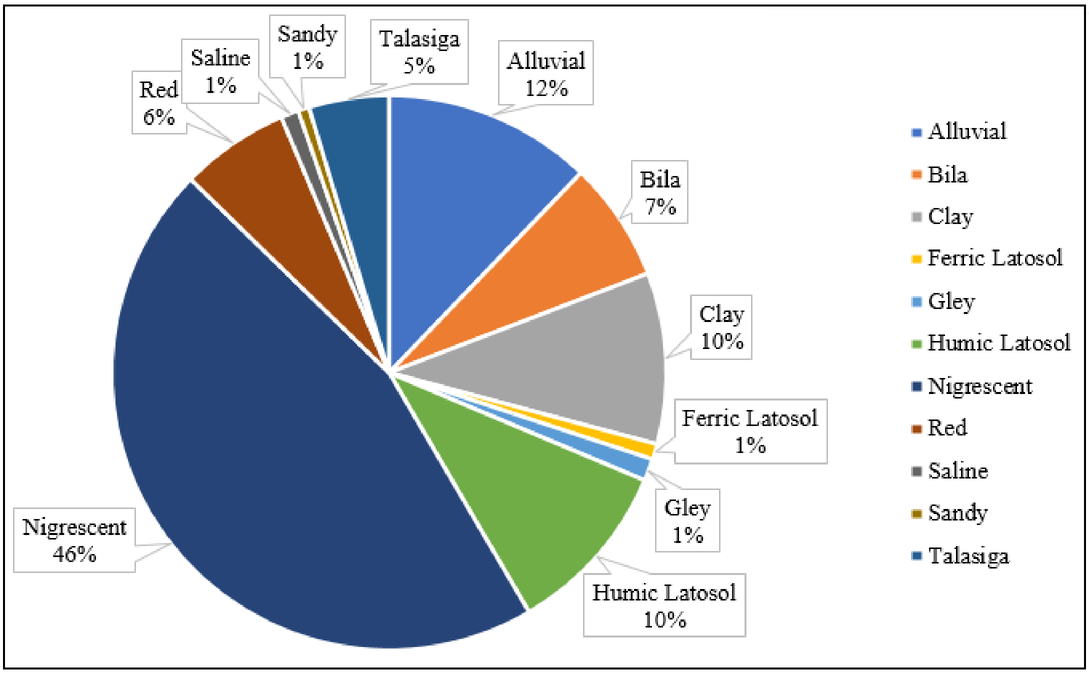

Figure 3: Percentage of the different soil types found in Viti Levu sugarcane belt areas.

A detailed comparison of the local soil types with international soil classification systems - the World Reference Base for Soil Resources (WRB) and USDA Soil Taxonomy - reveals important correlations and equivalencies across the study area.

Nigrescent soils, which dominate 46% of the landscape, typically correspond to Phaeozems in the WRB system and Mollisols in Soil Taxonomy. These soils are characterized by their dark surface horizons rich in organic matter, with high base saturation, making them naturally fertile for agricultural use. Their prevalence suggests significant agricultural potential in the region. Reference from “Community based climate change vulnerability assessment of the Sabeto Catchment, 2012” indicates that Nigrescent soils are moderately fertile to fertile. They are frequently cultivated and support a diverse range of crops in Fiji.

Alluvial soils (12%) correlate with Fluvisols (WRB) and Fluvents (Soil Taxonomy). These soils, formed from recent river deposits, are distinguished by their stratified nature and irregular distribution of organic matter with depth. The relatively high percentage of Alluvial soils indicates significant fluvial influence in the region's soil formation.

Clay soils and Humic Latosols each represent 10% of the area, with Clay soils corresponding to Luvisols (WRB) and Alfisols (Soil Taxonomy. Humic Latosols align with Ferralsols (WRB) and Oxisols (Soil Taxonomy), indicating areas of intense tropical weathering. Bila soils, comprising 7% of the area, require further local correlation studies for precise international classification alignment. Red soils (6%) typically correlate with Nitisols or Ferralsols (WRB) and Ultisols or Oxisols (Soil Taxonomy. These soils are usually highly weathered with significant iron oxide content.

The minor soil types also have important correlations:

Gley soils (1%) correspond to Gleysols (WRB) and various suborders of Inceptisols or Entisols with aquic conditions (Soil Taxonomy), Saline soils (1%) align with Solonchaks (WRB) and Salids (Soil Taxonomy) and Ferric Latosols (1%) correspond to Plinthosols or Ferralsols (WRB) and Oxisols (Soil Taxonomy).

This correlation with international classification systems enhances our understanding of these soils' properties and potential management requirements. The equivalencies provide a standardized framework for comparing soil properties and agricultural potential across different regions globally, facilitating the application of international research findings to local conditions.

4. Conclusion

A comprehensive analysis of 772 soil samples across Western Viti Levu's sugarcane belt revealed significant pH heterogeneity among eleven major soil types. The predominantly acidic nature of these soils, with 48% being acidic and 43% slightly acidic, indicates a widespread need for soil pH management in Fiji's sugarcane cultivation. Nigrescent soils emerged as the dominant soil type, comprising 46% of samples, while demonstrating moderate pH variability (SD=0.59). Clay soils exhibited the highest pH variability (SD=0.78), suggesting a need for more targeted management approaches in these areas. The study revealed significant spatial variations across sectors, with Lomawai recording the lowest pH values and Qeleloa the highest. These findings provide crucial baseline data for developing targeted soil management strategies in Fiji's sugarcane industry, particularly regarding lime application and crop management practices. Future research will prioritize expanding sampling of underrepresented soil types, particularly Sandy, Ferric Latosol and Saline soils, to develop a more comprehensive understanding of pH dynamics across all soil types in the region.

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