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Field-specific nitrogen management for sugarcane using electrical conductivity in-situ measurements

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Abstract

The study was conducted to determine the potential use of soil electrical conductivity (EC) in developing field-specific nitrogen fertilizer recommendation for sugarcane. Relationship of field EC (in-situ measurement) with other soil physico-chemical properties such as texture, cation exchange capacity (CEC), pH, total N, available P and exchangeable bases including K, Ca and Mg were established. Soil samples representing the following series; Guimbalaon (*Typic Hapludands*), Silay (*Aquic Hapludalfs*), Manapla (*Typic Hapludults*), Pulupandan (*Typic Ustipsamments*), San Manuel (*Typic Eutrudepts*), La Castellana (*Typic Humitrudepts*) and Bago (*Vertic Argiudolls*) in La Carlota Sugar Mill District, Negros Occidental, Philippines were studied. Significant positive relationships were observed between field EC and soil pH (r=0.51*), laboratory EC (r=0.59*), CEC (r=0.74**), clay content (r=0.74**) and exchangeable Ca (r=0.79**) and Mg (r=0.86**), while negative correlation was noted between field EC and sand content (r=-0.57*). The field EC measurements in relation to other soil physico-chemical properties were used to delineate boundaries and develop different management zones presented as EC map using GIS approach. This study suggests that field-specific N fertilizer application can be managed using field EC monitoring especially in large crop production areas such as in sugarcane wherein easy and rapid soil nutrient status monitoring is needed.

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Introduction

Soil electrical conductivity (EC) is a measure of the amount of soluble salts in soil and it is commonly expressed in units of milliSiemens per meter ($mS \cdot m^{-1}$). It affects crop yields, crop suitability, plant nutrient availability, and activity of soil microorganisms which influence key soil processes. Conventionally, soil scientist use EC to measure soil salinity. However, EC measurements also have the potential for estimating variation in some of the soil physical properties in a field where soil salinity is not a problem (Doerge, 1999). Soil EC has been related to soil properties affecting crop yield such as pH, water holding capacity, and salt concentrations (Doerge *et al.*, 2001), clay content and soil moisture (Kitchen *et al.*, 1999), depths of layer and organic matter content (Heiniger *et al.*, 2003; Doerge *et al.*, 2001). Thus, EC appears to be a pattern detector that can help define management zones where landscape features, such as topography and slope, may not provide obvious boundaries (Lund *et al.*, 2001; Franzen and Kitchen, 2000).

Although EC does not provide a direct measurement of specific ions or salt compounds, it is correlated to concentrations of nitrates, potassium, sodium, chloride, sulfate, and ammonia. For certain non-saline soils, EC determination can be a convenient and economical way to estimate the amount of nitrogen (N) available for plant growth. Using EC to estimate NO_3-N concentration has already been established (Zhang and Wienhold, 2002). EC has been useful also in monitoring nutrients in greenhouses and hydroponics (Samarakoon *et al.*, 2006).

The use of indirect and quick tests in diagnosing soil problems in terms of nutrient status and physical characteristics is essential in fertilizer management programs that would help reduce labor (soil sampling) and cost (laboratory analysis). In addition, evidence of EC relationship to other physical and chemical properties such as texture, pH, CEC, OM, N, P, and exchangeable bases such as Ca, Mg and K are limited. This study therefore aimed to establish the relationship of soil EC to other soil physicochemical properties and determine the potential use of soil electrical conductivity (EC) in developing field-specific nitrogen fertilizer recommendation for sugarcane.

Materials and methods

Study site

The study location was in La Carlota Sugar Mill District, Negros Occidental, Philippines covering three municipalities; La Castellana, Pontevedra, and La Carlota City. The district is geographically located between 10°18′0″ N, 122°51′0″ E and 10°27′0″ N, 123°9′0″ E at the south-western portion of Negros Occidental. It is bounded in the north by Bago City, in the east by the mountain ranges of Kanlaon Volcano and in the south by San Enrique.

Soil series validation

The different soil series within each of the study fields (Fld.) in La Carlota Sugar Mill District, Negros Occidental were validated through auger boring and soil profiling. The soil survey report of Negros Occidental was used to identify and validate the soil series. Soil map and Geographic Information System (GIS) were utilized to organize the distribution of soils and delineate their boundaries. The seven (7) major soil series (Guimbalaon, Silay, Manapla, Pulupandan, San Manuel, La Castellana, and Bago) and their distribution in La Carlota Sugar Mill District are presented in Fig. 1.

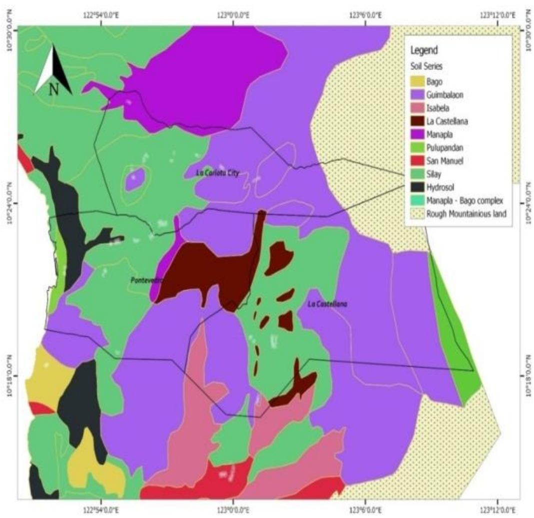

Fig. 1. Soil map of La Carlota Sugar Mill District, Negros Occidental, Philippines.

Soil sample and field EC data collection

The soil samples were collected on 16 sugarcane fields, which in part were selected to represent the seven soil series present in the mill district.

Soils of the study fields exhibited differences in terms of texture, parent material, and mineralogy. Taxonomic descriptions of the soils in the study fields are given in Table 1. Soil samples were collected through grid sampling (100mx100m) within each field. Number of soil samples collected from each series varied depending on the number and size of fields. For each soil sampling point, approximately 500g of soil was taken at a depth of 0-30cm. Three field EC readings were taken simultaneously using Activity Meter PNT 3000.

Table 1. Taxonomic description of the soil series in La Carlota Sugar Mill District.

Soil series	Taxonomic description
Guimbalaon	Fine clayey, mixed, isohyperthermic, Typic Hapludands
Silay	Fine loamy, mixed, isohyperthermic, Aquic Hapludalfs
Manapla	Very fine, isohyperthermic, Typic Hapludults
Pulupandan	Mixed, isohyperthermic, Typic Ustipsamments
San Manuel	Fine loamy, mixed, isohyperthermic Typic Eutrudepts
La Castellana	Very fine clayey, isohyperthermic Typic Humitrudepts
Bago	Fine, montmorillonitic, isohyperthermic Vertic Argiudolls

Soil analysis

Soil physical and chemical laboratory analyses were conducted at Soil Chemistry Laboratory, Soils and Agro-Ecosystems Division – Agricultural Systems Cluster (SAED – ASC), College of Agriculture (CA), University of the Philippines Los Baños (UPLB). Analytical Services Laboratory (ASL) standard procedures for determining soil properties such as texture, pH, CEC, OM, total N, available P, and exchangeable bases such as Ca, Mg and K were followed.

Data analysis

Using GIS approach, spatial variability of the various soil physical and chemical properties [e.g. electrical conductivity, soil pH, organic matter (OM) content, total nitrogen (N), available phosphorus (P) and exchangeable bases] were plotted. The Global Positioning System (GPS) readings were taken to determine the location of the sampling points.

The geo-referenced points within soil series and field were used to obtain the needed information for mapping and zoning such as elevation and slope. The geo-referenced soil sampling points were interpolated by means of Ordinary Kriging (OK) to produce contour maps of the distribution of soil texture, pH, EC, OM, CEC, total N, available P and exchangeable bases (Ca, Mg and K). The contour maps were used in nutrient management zone delineation. The zoning was done through ordinary kriging (OK) or the optimal interpolation based on regression against (z) values of the surrounding data points and is weighted according to spatial covariance values. Correlation and multi-regression analyses of all the data gathered were done using STAR or Statistical Tool for Agricultural Research.

Results and discussion

Soil physico-chemical properties

Soil texture

Textural class of the soils ranged from sandy loam to clay (Table 2). Guimbalaon, San Manuel and La Castellana are the series with high amount of clay. In general, these soils have higher CEC than sandy soils (Bago and Manapla series). Texture is one of the soil properties aside from amount and type of clay and OM content, which determines CEC. Unlike sand and silt, clay particles have the largest negatively charged surface area and chemically the most active in terms of attracting and storing plant nutrients. Although sugarcane can grow over a wide textural range of soils, usually sandy clay loam soils (20 to 35% clay), tend to be the more productive soils (Meyer *et al.*, 2011).

Soil EC

The field EC measurements ranged from 0.08 to 0.63mS·m^{-1} while those analyzed in the laboratory ranged from 0.08 to 0.34mS·m^{-1} (Table 2). The low levels of soil EC indicate that all the soils tested were low in soluble salts or were non-saline. In situ measurements of EC (field EC) were relatively higher compared to EC measured in the laboratory. Moreover, differences in EC among the series were higher in situ compared with measured in the laboratory. This could be due to the type and amount of clay, water content, temperature, and ion concentration affecting soil EC measurements

(Zhang and Wienhold, 2002). Laboratory measurements of EC were done under standardized conditions, water content and temperature effects were removed. Under the same soil series, the amount of clay is similar and changes in laboratory measured EC are due to changes in ion concentrations. Field EC was taken under varying moisture conditions and thus reflects differences in water content as well as ion concentration. The highest field and laboratory EC was recorded in San Manuel and Pulupandan series (0.63 and 0.34mS·m^{-1}, respectively).

Table 2. Means and standard deviations (SDs in parentheses) of soil physico-chemical properties obtained from the study fields in La Carlota Sugar Mill District.

Series	Study field	Field EC, mS·m^{-1}	Lab EC, mS·m^{-1}	pH	OM, %	Total N, %	N mineralization rate, ppm·day^{-1}
Guimbalaon	San Miguel	0.20 (0.06)	0.11 (0.02)	5.7 (0.25)	2.2 (0.32)	0.09 (0.01)	9.69
	Salamanca	0.31 (0.08)	0.13 (0.06)	5.6 (0.56)	2.3 (0.71)	0.07 (0.02)	13.27
	Canman-og	0.27 (0.08)	0.13 (0.04)	5.3 (0.32)	2.1 (0.43)	0.08 (0.01)	4.41
	Alipion	0.36 (0.09)	0.14 (0.04)	5.5 (0.12)	2.5 (0.15)	0.05 (0.01)	8.79
	Mean	0.29 (0.08)	0.13 (0.04)	5.5 (0.31)	2.3 (0.40)	0.07(0.01)	9.04
Silay	Milagrosa	0.08 (0.08)	0.08 (0.04)	5.0 (0.20)	2.6 (0.14)	0.08 (0.04)	8.77
	Sua	0.30 (0.13)	0.16 (0.03)	5.4 (0.26)	2.3 (0.42)	0.09 (0.02)	8.90
	Carmencita	0.13 (0.07)	0.08 (0.02)	5.1 (0.38)	3.4 (1.33)	0.09 (0.04)	7.82
	Carmen grande	0.11 (0.10)	0.07 (0.02)	5.8 (0.33)	4.3 (1.33)	0.09 (0.04)	8.73
	Esperanza	0.22 (0.06)	0.09 (0.04)	5.6 (0.32)	3.1 (0.58)	0.06 (0.02)	5.87
	San Francisco	0.23 (0.10)	0.09 (0.04)	5.3 (0.63)	2.2 (1.35)	0.08 (0.02)	6.11
	Cristina	0.25 (0.05)	0.15 (0.03)	5.2 (0.27)	2.2 (0.32)	0.13 (0.02)	-
	Mean	0.19 (0.08)	0.10 (0.03)	5.3 (0.34)	2.9 (0.78)	0.09 (0.03)	7.7
Bago	Dinandan	0.09 (0.06)	0.09 (0.04)	5.3 (0.61)	2.2 (0.72)	0.08 (0.01)	8.90
Manapla	Ayungon	0.13 (0.04)	0.07 (0.01)	5.0 (0.26)	1.6 (0.15)	0.07 (0.02)	8.99
Pulupandan	Canroma	0.43 (0.14)	0.34 (0.05)	7.7 (0.18)	4.2 (0.30)	0.13 (0.02)	6.46
San Manuel	Progreso	0.63 (0.09)	0.16 (0.03)	6.0 (0.31)	2.6 (0.37)	0.08 (0.01)	8.66
La Castellana	V. Malaga	0.12 (0.09)	0.08 (0.02)	5.6 (0.28)	5.4 (1.42)	0.13 (0.06)	12.59

Table 2 continued

Series	Study field	Avail. P, ppm*	Exchangeable Bases			CEC, cmol$_c$·kg^{-1}	Textural Class
			Exch. K, cmol$_c$·kg^{-1}	Exch. Ca, cmol$_c$·kg^{-1}	Exch. Mg, cmol$_c$·kg^{-1}		
Guimbalaon	San Miguel	30.4 (9.73)	2.11 (1.05)	6.41 (2.19)	8.00 (2.99)	23.2 (3.02)	L – C
	Salamanca	21.6 (11.8)	0.82 (0.44)	8.55 (3.31)	10.6 (3.54)	20.9 (4.67)	L - C
	Canman-og	33.2 (11.7)	1.14 (0.36)	13.2 (2.62)	14.1 (3.93)	27.4 (3.07)	CL- SCL
	Alipion	47.1 (18.0)	0.78 (0.30)	12.5 (2.20)	15.9 (2.98)	28.8 (3.10)	CL - C
	Mean	33.1 (12.8)	1.21 (0.54)	10.2 (2.58)	12.2 (3.36)	25.1 (3.46)	
Silay	Milagrosa	3.23 (1.67)	0.40 (0.02)	6.25 (3.27)	8.23 (3.55)	21.8 (7.37)	L - C
	Sua	44.5 (5.54)	0.39 (0.07)	10.9 (2.29)	13.1 (2.25)	23.6 (3.62)	L - SCL
	Carmencita	28.3 (14.2)	0.79 (0.38)	6.99 (2.32)	8.29 (3.02)	24.5 (3.89)	SL-SiCL
	Carmen grande	38.1 (15.1)	1.07 (0.53)	6.33 (2.00)	8.54 (2.26)	20.8 (3.88)	SL-SCL
	Esperanza	34.7 (14.3)	1.55 (0.68)	8.57 (2.69)	10.9 (3.19)	21.4 (4.09)	L - SCL
	San Francisco	4.40 (16.3)	0.35 (0.70)	6.89 (1.57)	9.80 (1.29)	18.6 (2.79)	L - SCL
	Cristina	35.7 (8.62)	0.57 (0.30)	9.26 (2.26)	12.4 (3.24)	27.0 (4.50)	L - CL
	Mean	27.0 (10.8)	0.73 (0.38)	7.88 (2.34)	10.2 (2.68)	22.5 (3.75)	
Bago	Dinandan	4.36 (2.91)	0.35 (0.11)	7.44 (4.33)	8.19 (3.85)	18.6 (3.21)	SL- SCL
Manapla	Ayungon	18.0 (5.82)	0.33 (0.12)	6.56 (1.00)	8.92 (0.78)	20.8 (1.78)	SCL
Pulupandan	Canroma	12.5 (12.4)	0.50 (0.35)	34.6 (5.02)	32.1 (3.03)	39.6 (6.45)	SL-SCL
San Manuel	Progreso	36.0 (16.0)	1.10 (0.63)	23.0 (5.34)	25.8 (3.94)	43.5 (5.64)	CL – C
La Castellana	V. Malaga	30.4 (17.7)	1.22 (0.73)	7.66 (3.27)	8.74 (3.57)	28.9 (6.22)	SL – SCL

*Pulupandan series – Olsen method for P determination is used.

Soil reaction (pH)

Soil pH (Table 2) varied from a range of 5.0 (strongly acidic) to 7.7 (moderately alkaline) which is considered desirable for sugarcane (Meyer *et al.*, 2011). The seven (7) soil series were classified as highly acidic except for Pulupandan and San Manuel series.

This could be explained by the calcareous nature of Pulupandan series. Calcareous soils are characterized with pH greater than neutral, typically 7.5 to 8.5, having the presence of significant quantities of free excess lime as calcium or magnesium carbonate (Hopkins and Ellsworth, 2005). Lime dissolves in neutral to acid pH soil, but does not readily dissolve in alkaline soil and, instead, serves as a sink for surface adsorbed calcium phosphate precipitation.

Organic matter (OM), total N & mineralization potential

OM ranged from 1.6 (Manapla series) to 5.4% (La Castellana series). Highest OM content (5.4%) and total N (0.13%) were recorded in La Castellana series (Table 2). Organic matter is an indicator that determines level of CEC, since it has greater CEC than a similar mass of clay, giving it a strong capacity to attract nutrients and to act as a potential source on N, P and S through mineralization. Soils containing higher amounts of OM generally are capable of releasing higher quantities of nitrogen. Thus, high CEC and a high rate of N mineralization (12.59 $ppm{\cdot}day^{-1}$) was also recorded from this series. High OM however does not necessarily result to high mineralization rate. Sites with high OM but with low N mineralization rates were Canroma (Pulupandan series), Carmencita and Carmen Grande (Silay series). There are instances that high OM can even reduce the mineralization rate due to recalcitrant OM conversion in the case of anaerobic condition (Castillo *et al.*, 2010). The highest N mineralization rate was noted in one site in Guimbalaon series (Salamanca) that has lower OM level (Table 2). This could be due to other factors affecting N mineralization such as drying and wetting cycles, the duration of drying prior to wetting up, temperature changes, soil pH, biological activity and soil disturbance through tillage operations (Meyer *et al.*, 2011). Guimbalaon series is known to have moderate to high mineralization potential index.

Available P

The soil phosphorus levels (Table 2) ranged from 4.36ppm (Bago series) to 36.0ppm (San Manuel series). Medium level of available phosphorus (P) was noted in Pulupandan series with 12.5ppm (Olsen method), while San Manuel series has medium to high levels of P (36.0 to 47.2ppm) using Bray method. Manapla and La Castellana series have medium P levels, while Guimbalaon and Silay have low to medium P levels. In the case of Pulupandan series which has a pH of 7.7, phosphorus availability is low (12.5ppm). If the pH is too high, phosphate ions will dominate which will become prone to precipitation by soluble forms of Ca and Mg. In Silay series, however, two study fields Milagrosa and San Francisco exhibited low available P (3.23 and 4.4ppm, respectively). The low levels of P in these two sites could be attributed to pH levels of 5.0 and 5.3, respectively. Under acidic conditions, phosphorus becomes compounded into insoluble forms with Fe and Al as ferric hydroxyphosphate and aluminium hydroxyphosphate. Bago series also has low P availability. This could be explained by the acidic nature of these soil types which promotes strong P-fixation by iron and aluminum oxides.

Exchangeable K

Exchangeable K (Table 2) ranged from 0.33 to $2.11cmol_c{\cdot}kg^{-1}$, high level in Fld. San Miguel (Guimbalaon series) with $2.11cmol_c{\cdot}kg^{-1}$ and low level in Fld. Ayungon (Manapla series) with $0.33cmol_c{\cdot}kg^{-1}$. Bago series also has low level of exchangeable K with $0.35cmol_c{\cdot}kg^{-1}$. This soil series is known to have low K capital reserves or K deficiency. Unlike N and P, K in the soil is predominantly present in inorganic forms, in minerals such as feldspars and micas. However, actual plant available K levels may be low due to the low solubility of K in the mineral composition of the soil (Meyer *et al.*, 2011).

High level of K was observed in Pulupandan, San Manuel, and La Castellana series. However, there were varying levels of K (low to high) within Manapla, Guimbalaon and Silay series. An imbalance in the soil K equilibrium can occur when there is an over-exploitation of soil K reserves, and application of fertilizer K results in a shift where applied fertilizer K will be fixed by K selective clay minerals within the clay lattice. These soils exhibit strong K-fixing properties, containing a high proportion of K selective clay minerals such as smectite and vermiculite.

Exchangeable Ca and Mg

Exchangeable Ca ranged from 6.25cmol$_c$·kg^{-1} to 34.6cmol$_c$·kg^{-1} (Table 2). The range was low to high at the range of 5.0 to 6.0 pH of the soil series tested. Soil pH is a strong indicator of exchangeable Ca availability in soils, ranging from levels of deficiency below a pH of 4.5 to sufficiency above a pH of 7.5. Only Pulupandan series with a high exchangeable Ca, 34.6cmol$_c$·kg^{-1} has a sufficient level of Ca. This can be explained by its calcareous nature and high pH levels. Fld. Canman-og (13.2cmol$_c$·kg^{-1}) and Alipion (12.5cmol$_c$·kg^{-1}) under Guimbalaon series and Fld. Sua (10.9cmol$_c$·kg^{-1}) of Silay series have low levels of exchangeable Ca. San Manuel series with pH of 6.0 has medium level of exchangeable Ca (23.0cmol$_c$·kg^{-1}). Calcium deficiencies are observed in all series except for Pulupandan and San Manuel series, although Ca levels of the latter is almost at the critical level. Magnesium, like Ca is also a significant determinant for nutrient management in acid soils. The levels of Mg in the soil series tested were found to be high (Table 2). The range of exchangeable Mg was from 8.0cmol$_c$·kg^{-1} (Guimbalaon series) to 32.1cmol$_c$·kg^{-1} (Pulupandan series). These Mg levels were classified from a range of low to high. Low levels of Ca were observed in Guimbalaon (San Miguel and Salamanca), Silay (except for Sua and Cristina), Bago, Manapla and La Castellana.

However, other sites of these series were noted to have critical Mg levels (12.4 to 15.9cmol$_c$·kg^{-1}). Similar to Ca, high levels of Mg were only observed in San Manuel (25.8cmol$_c$·kg^{-1}) and Pulupandan series (32.1cmol$_c$·kg^{-1}). The content and forms of Mg found in soils are largely determined from the geological parent material from which the soil was derived, climate which determines the degree of weathering and position of the soil in the landscape. In general, soils derived from igneous and metamorphic rocks (Pulupandan and San Manuel series) containing the minerals olivine, biotite, hornblende and chlorite tend to be well supplied with Ca and Mg (Wood and Meyer, 1986), whereas soil from sedimentary rocks such as sandstones (Guimbalaon, SIlay, Bago, Manapla and La Castellana) are quickly exhausted of Ca and Mg, as well as most other nutrients.

CEC

The CEC values obtained from all the sampling sites were generally high (Table 2). However, relatively higher CEC values were recorded from Pulupandan and San Manuel series. These soil series have 39.6 and 43.5cmol$_c$·kg^{-1}, respectively. This observation corresponds to high levels of Ca, Mg and K in these two soil series. CEC also reflects the capacity of a soil to retain and release elements such as K, Ca, Mg, and Na. In addition, these soils also have high organic matter which also contributed to a higher CEC.

Relationship of field EC with other soil physico-chemical properties

Electrical conductivity (EC) is a measure of soluble salts in soil and is being used recently in nutrient management programs and other agricultural usage. It can be directly measured in the field using a portable EC meter or in the laboratory. Table 3 shows the relationships (r) of field EC with the soil chemical and physical properties. Considering all soil series, field EC was significantly correlated to laboratory EC, pH, cation exchange capacity (CEC), exchangeable calcium (Ca) and magnesium (Mg), and clay and sand content. This result conforms to the study of Golhar and Chaudhari, 2013 indicating that EC measurements in the field using portable EC meter can be used to predict the soil parameters mentioned.

Laboratory EC

There is a moderate relationship (r=0.59*) between lab and field EC when all series were considered (Table 2). Very strong relationship was noted in Pulupandan (r=0.93**) and Bago (r=0.95**), while moderate relationship was observed in Guimbalaon (r=0.41*), Manapla (r=0.45*) and San Manuel series (r=0.46*). The lab EC of these latter soil series were relatively lower (Table 3).

Soil reaction (pH)

Generally, there was a significant relationship observed between field EC and soil pH (r=0.51*). The negative significant correlation (Table 3) between field EC and pH was only observed in Pulupandan series (r=-0.67**) which has a minimum and maximum pH of 7.4 and of 7.9, respectively (Table 2).

Significant positive relationships were observed in Guimbalaon (r=0.40*) and Bago series (r=0.88**). It can be inferred that when soil pH increases or becomes alkaline, field EC value decreases.

Table 3. Correlation coefficients (r) between field electrical conductivity (EC) and other soil properties by soil series.

Soil Property	Guimbalaon	Silay	Bago	Manapla	Pulupandan	San Manuel	La Castellana	G,S,B,M, SM,L*	All Series
Lab EC, mS m^{-1}	0.41	0.56	0.95	0.45	0.93	0.46	0.55	0.69	0.59
pH	0.40	0.38	0.88	-0.35	-0.67	0.28	-	0.58	0.51
OM, %	-	-0.49	-	-	0.34	-0.52	-0.43	-0.39	-0.35
Total N, %	-0.30	-0.21	-0.35	0.29	-	-	-0.43	-0.28	-0.23
Avail P, ppm	-	0.32	0.42	-	-0.44	-	-	0.23	-
Exch K, cmol$_c$ kg^{-1}	-0.34	-	0.36	-	-0.30	-	-	-	-
Exch Ca, cmol$_c$ kg^{-1}	0.45	0.63	0.98	-0.37	0.73	0.33	0.62	0.87	0.79
Exch Mg, cmol$_c$ kg^{-1}	0.63	0.67	0.94	-	0.77	0.56	0.71	0.61	0.86
CEC, cmol$_c$ kg^{-1}	0.40	-	0.76	0.90	0.43	0.48	-0.18	0.74	0.74
Clay, %	-	0.50	0.63	0.34	0.40	0.51	0.82	0.70	0.67
Silt, %	0.25	-	0.36	-	0.32	-	-	-	-
Sand, %	-0.28	-0.43	-0.63	-0.28	-0.49	-0.37	-0.31	0.63	-0.57

All correlations are highly significant ($\rho<0.001$) except on (-) items.

*All soil series except for Pulupandan series.

OM content

There was no relationship between field EC and OM content in Guimbalaon, Bago, Manapla and Pulupandan series. In the case of La Castellana, Silay and San Manuel series (Table 3), negative significant relationship between OM content and field EC (r=-0.43*, -0.49* and -0.52*, respectively) were noted. Soils with relatively higher OM content tended to have lower EC values.

Total N

Similar to OM content, no significant relationship was recorded for total N and field EC. Significant negative relationship was only observed in La Castellana series (r =-0.43*) as shown in Table 3. This may be attributed to the high total N content of these soils and its loamy texture (Table 2). Relatively low field EC was recorded in this series.

Available P

Significant positive relationship (r=0.42*) between field EC and available P was only observed in Bago series, while significant negative relationship (r=-0.44*) was noted in Pulupandan series (Table 3). Low levels of available P in Pulupandan series is due to high P fixation by Ca and Mg. Thus for this type of soil, increased in EC could mean decreased in availability of P. Variability in available P measurement could be due to variability in soil properties including texture, soil moisture and temperature.

Exchangeable K

Generally, no significant relationship was observed between EC and exchangeable K (Table 3). Variations in measures of exchangeable K could be due to inherent characteristics of the soil series studied, such as strong K-fixing properties for soils containing high proportion of K selective clay minerals like smectite and vermiculite.

Exchangeable Ca & Mg

As shown in Table 3, highly significant positive relationship between field EC and exchangeable calcium was observed in all soil series combined (r=0.79**).

The contributing series were Guimbalaon (r=0.45*), Silay (r=0.63**), Bago (r=0.98**), Pulupandan (r=0.73**) and La Castellana (r=0.62**). Only in Manapla and San Manuel series did the weak relationships exist. These series has both sandy loam texture and are characterized to have weak structures that promote reduced nutrient retention. These soils are also classified with low nutrient capital reserves and low CEC. During field EC measurements, the reading was affected by soil texture, moisture and structure. Correlation of field EC with exchangeable magnesium was highly significant (r=0.86*) in all the soil samples (Table 3). However, there was no significant relationship observed in Manapla series. This series had soil pH range of 5.7 to 6.3 (Table 2).

CEC & clay content

Strong positive correlation was observed in all the soils tested for field EC and CEC (r=0.74**) as shown in Table 3. The higher the CEC, the higher the field EC values obtained. The significant relationship between field EC and clay content (r=0.74*) is a clear account of the relationship between of clay content and CEC. The higher the clay content of the soil, the higher the EC values obtained. All the soil series combined showed significant relationship, however, when analyzed by series, Guimbalaon and Manapla soil series showed no significant correlation. Since CEC determines the type and amount of active materials in the soil and the nature of absorbing material through clay mineralogy and soil pH, soils with high clay content and CEC are more capable of holding large quantities of available nutrients, thus it is expected that lower rate of fertilizer will be recommended for these type of soils.

Silt & sand Content

Sand content showed significant negative relationship with field EC in general. This was inversely related to the values obtained in clay percentage of soils. However, no relationship was observed in Guimbalaon, Manapla, San Manuel and La Castellana series. These series have loam to sandy loam texture, thus silt percentages of the soils also vary. For silt content, in general, no significant relationship was observed.

Nitrogen management & EC zones

Based on the significant relationship of EC with pH, CEC, clay & sand content, and exchangeable Ca & Mg, discussed in the previous sections, EC alone can be used to define variability within each field. Soil electrical conductivity and elevation data were used to generate the six (6) zones shown in Fig. 2. The four (4) soil EC ranges used were 0.01 – 0.24, 0.25 – 0.50, 0.51 – 0.74 and 0.-75-0.99mS·m^{-1}. Elevation ranged from 0-75, 76-150 and 150-225mASL. These EC zones can be used in a site-specific manner to improve fertilizer efficiency by assisting in determining the availability of nutrients in the soil and estimating the amount of nutrient needed by the crop. Using technologies such as global positioning system (GPS), geographic information system (GIS), and soil electrical conductivity (EC) mapping, sugarcane growers can sample and record geo-referenced field characteristics with 1- to 3-m accuracy and fertilizer rates can vary to more closely meet the site-specific demands of the crop. This will not be the same case when only one recommendation rate are being used in a 50 hectare field with obviously different nutrient requirements. The latter poses an economical problem to growers because of sometimes over-application of fertilizers to areas already containing high amounts of nutrients. Thus, variable-rate nitrogen fertilizer recommendation would be needed.

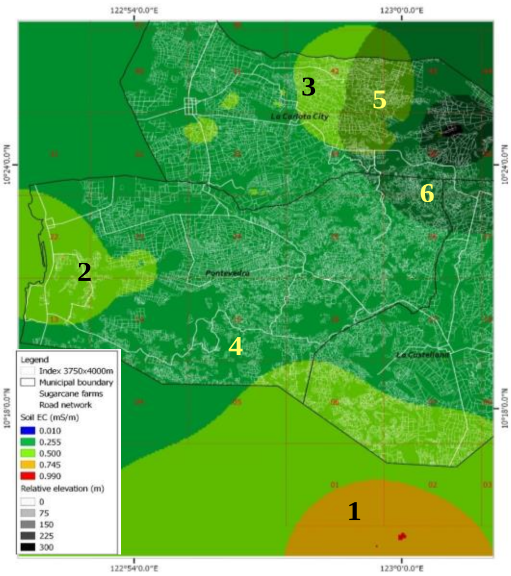

Fig. 2. Soil EC zones in La Carlota Sugar Mill District.

Variable-rate nitrogen fertilizer recommendation

The OM content and mineralizing capacity of the soils sampled in La Carlota Sugar Mill District is shown in Table 4.

Nitrogen mineralization capacity of Pulupandan and La Castellana series were high and very high, respectively. The different study fields under Silay series exhibited moderate to moderately high N mineralizing capacity, Guimbalaon and San Manuel series had moderate and Manapla had low capacity to mineralize N. Mineralization potential analysis was only done in one study field per series. Thus the recommendation was only limited to soil series and study field level. Organic matter, mineralization, clay percentage, moisture and yield target were the basic factors considered for the recommendation rates generated. Comparison between the two recommendations was presented in Table 5. Generally, higher rates of N were recommended based on SRA formulation. The range of increase of N recommendations was from 6kg·ha^{-1}N (La Castellana series of Fld. V. Malaga) to 53kg·ha^{-1}N (Guimbalaon series of Fld. Alipion). Almost the same rate was recommended for Fld. Cristina (Silay series) using the two formulations. The increase of N rate recommended by SRA would be very significant in terms of labor cost of fertilizer application and the fertilizer cost per se. Thus field validation of these results should be conducted.

Table 4. Mineralizing capacity of the soil series in La Carlota Sugar Mill District.

Series	Study field	OM (%)*	N mineralizing capacity**
Guimbalaon	San Miguel	2.2	Moderate
	Canman-og	2.1	Moderate
	Alipion	2.5	Moderate
	Salamanca	2.3	Moderate
Silay	Milagrosa	2.6	Moderate
	Sua	2.3	Moderate
	Carmencita	3.4	Moderately high
	Carmen Grande	4.3	High
	Esperanza	3.1	Moderately high
	San Francisco	2.3	Moderate
	Cristina	2.2	Moderate
Bago	Dinandan	2.2	Moderate
	Ayungon	1.6	Moderate to Low
Pulupandan	Canroma	4.2	High
San Manuel	Progreso	2.6	Moderate
La Castellana	V. Malaga	5.4	Very high

* Based on laboratory analysis (actual)

**Based on general recommendations for N application in Australia (Schroeder *et al.*, 2005).

Table 5. Variable-rate nitrogen fertilizer recommendation (kg•ha^{-1}) for sugarcane production in La Carlota Sugar Mill District based on mineralization potential and SRA formulation*

Series	Study field	Nitrogen Fertilizer Rate (kg·ha^{-1})	
		Based on mineralization index	Based on SRA Formula
Guimbalaon	San Miguel	120	147
	Canman-og	120	154
	Alipion	120	173
	Salamanca	120	164
	Mean	120	160
Silay	Milagrosa	120	154
	Sua	120	149
	Carmencita	110	146
	Carmen Grande	100	144
	Esperanza	110	165
	San Francisco	120	163
	Cristina	120	121
	Mean	115	149
Bago	Dinandan	120	150
Manapla	Ayungon	130	156
Pulupandan	Canroma	100	118
San Manuel	Progreso	120	157
La Castellana	V. Malaga	100	106

*Yield target of 100 tc·ha^{-1}

Nitrogen recommendation for EC Zones

The total N content of the soils in each EC zones (Fig. 2) is presented in Fig. 3. The resulting fertilizer N recommendation for each zone using mineralization potential and the formulation developed by SRA is presented in Fig. 4.

As shown in Fig. 4, the range for mineralization potential-based is from 115 to 120kg·ha^{-1}N and 140 to 163kg·ha^{-1}N for SRA-based. N fertilizer recommendations based on mineralization potential were lower compared to SRA recommendations. The lower recommendation rates of the former were due to indigenous nutrient supply (INS) considerations. Most of sugarcane N requirement came from nitrogen that is made available through the mineralization of soil organic matter as well as fertilizer inputs. However, only about one third of the nitrogen applied as fertilizer is being taken up by the crop. The rest of the nitrogen goes into the soil reserves or is lost by leaching. Studies conducted in South Africa, Australia, Brazil and Florida have shown that OM and soil mineralization potential have an important effect on the N requirement of sugarcane (Meyer *et al.*, 2011).

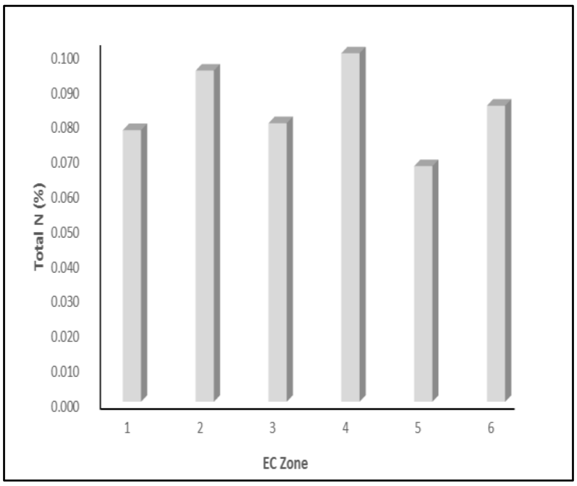

Fig. 3. Total N (%) from each EC zone in La Carlota Sugar Mill District (Fig. 2).

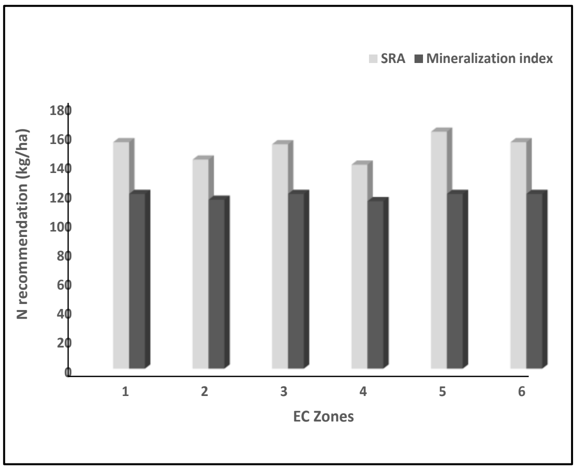

Fig. 4. Nitrogen fertilizer recommendation (kg•ha^{-1}) for each zone in Fig. 2.

Conclusion

All the soils tested are non-saline which is recommended for sugarcane production. Strong positive correlation was established in all the soils tested between field and laboratory EC, soil pH, CEC, clay content and exchangeable Ca and Mg. Relating the soil parameters studied, field EC monitoring can be used to define variability within the field thus improving fertilizer rates to more closely meet the field-specific demands of the crop. Although field validation is still needed for the generated variable-rate nitrogen fertilizer recommendation, this study suggests that field-specific N fertilizer application can be managed using soil EC especially in large crop production areas such as in sugarcane.

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