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Establishing a soil reference system for fertility assessment and monitoring at plot level in the highlands of Mindanao, Philippines

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Abstract

The study was conducted in the crop production areas of Miarayon Village, along the volcanic footslope of Mt. Kalatungan, Talakag, Bukidnon, Philippines. The elevation range of the longitudinal toposequence is 1,900 to 1,300 m asl. Production areas in the intermediate part of the toposequence (Salsalan) are located at about 1,600 to 1,400 m asl and in the lower part (Mambuaw) at 1,400 to 1,300 m asl. A total of 24 plots (12 in each location) which were planted to potatoes, carrots and corn were investigated. Soils are "Andic" Cambisol in open and convex positions and "Andic" Umbrisol in concave positions and toeslopes. The soil pH values ranged from 5.0-5.9. TOC and TN content were medium to high (4.1-8.9% and 0.30-0.80% respectively) with C/N ratios from 8-15. Range values of available Ca, Mg, K and Na were 1.9-11.24, 0.16-2.14 and 0.20-1.13, 0.04-0.13 $cmol_{+}kg^{-1}$, respectively. Top soil horizon exchangeable Al in Mambuaw was higher than in Salsalan. The differences in TN, C/N ratio and available K levels between the two locations were very highly significant, TOC was highly significant and for soil pH and available Ca and sum of bases, their disparities were significant. Available Mg and Na did not differ between the two sites. Mean potato yield in Salsalan was 8.97 tha^{-1} more than in Mambuaw. Mean carrot yield in Salsalan was 2.39 tha^{-1} lesser than in Mambuaw. Mean corn yield in Salsalan was higher than in Mambuaw by 0.29 tha^{-1} only. Correlations between potato yields with TOC, TN, and available Ca were highly significant while soil pH and K were significant. There was no relationship detected between potato yields and Mg and Na. There was no association detected between carrot yields with topsoil nutrient levels. Correlations were noted in corn yields with available Ca, Mg and K.

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Introduction

The Philippine archipelago has a total land area of 30M ha and its economy is rooted in agriculture. The rising demand of land for food production had taken in the last century, from a sparsely 28 cap km^{-2} in 1910 to a densely populated of 273 cap km^{-2} in 2003 (Kastner and Nonhebel, 2009) and the country's population density had increased by 20.7% from 2010-2012 (NSO, 2012). The promotion of agriculture and timber industry in the past had paved the way for migrants to cultivate the soil in Bukidnon (Lao, 1992). In recent decades, the stabilization of the lowlands intensification and the failure of industrialization to absorb labor surplus has led to a major migration of subsistence farmers into the marginal uplands (Cramb, 2005). Farmers plant crops continuously and apply fertilizers without assessing the current soil fertility.

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Application rates depend on how much resources the farmers have and therefore under or over application of these inputs can happen. Reports revealed that most of Mindanao soils are of volcanic origin, however, studies on physico-chemical and mineralogical properties, genesis and classifications were scarce (Bacatio et al., 2005). Although data on crop production are available, the relationships between soil characteristics and plant response including its nutrient assimilation are not studied.

It is imperative for land users to know the capacity of the soil that supports intensive agriculture. A soil reference system (SRS) guides decision making towards an agro-environmentally sound soil management. The SRS is an important component of a Land Information System (LandIS) which facilitates objective and scientifically based land use decisions. A LandIS is the pooling of information which is prerequisite to land resource surveys for physical land appraisal which can be used for land suitability evaluation (FAO, 1989). To deliver precise soil information to crop plot users, one has to go down to plot level in gathering data. The SRS is the integration of field and laboratory data, crop yields and plant response assessment as tool to assess and monitor soil fertility.

This study is a component of the development of a generic protocol for a LandIS for land use planning in the highlands of Mindanao Philippines which adopted the framework and methodology in Bock (1994). The objective of this study was to build an SRS for soil fertility assessment and monitoring and specifically sought to: (1) determine the basic nutrients for topsoil fertility assessment and monitoring of representative plots in two locations by topsoil composite samples analyses, (2) find out the crop yields in plots where topsoil composite samples were taken, and (3) verify the association of topsoil analyses results with crop yields.

Material and Methods

Study Area Description

This study was carried out in Miarayon, Talakag, Bukidnon in the island of Mindanao, the Philippines. Miarayon is situated at the foot of the northwest side of Mt. Kalatungan. Mt. Kalatungan is a Quaternary volcano which is mostly basaltic and pyroclastic in character and analyses of its rock samples revealed that these are calc-alkaline dacite, calc-alkaline basalt and shoshonitic basaltic andesite (Sajona et al., 1997). The piedmont is dissected with permanent streams and watercourses. Preliminary investigation had identified the relationships between rock, soil, relief and land use along the longitudinal toposequence excepting the summit under forest. The long volcanic footslope was divided according to relief and elevation into upper part (1,900 to 1,600 m asl), the intermediate part (1,600 to 1,400 m asl) and the lower part (1,400 to 1,300 m asl).

The center of Miarayon where the community is concentrated is located at an elevation of approximately 1,450 m asl at 5 to 10% slope. The permanent fields have thick brownish black (10YR2/2 to 2/3) topsoil. Dominant crops grown are potatoes (*Solanum tuberosum* Linn.), carrots (*Daucus carota var. sativus*) and corn (*Zea mays* Linn.). Potatoes and carrots are cash crops and corn is for household consumption. The initial groundwork had identified nine pedon locations. However, in this study, the surrounding plots around four pedon locations, P_4 and P_5 of the intermediate part (Salsalan) and P_7 and P_8 in the lower part (Mambuaw) were taken into consideration because these are the locations where Miarayon production areas are concentrated. Mambuaw is the site of the old Miarayon settlement in which according to farmers had been intensively cultivated since earlier than 1950s. Salsalan is the later hamlet location where the plots are cultivated recently. It can be seen that newly opened production plots are advancing towards the upslope.

The thirty-year mean annual rainfall recorded at Malaybalay Weather Station, Bukidnon is 2,569 mm with wettest months from July to October (PAGASA-DOST, 2014). Mean annual temperature and relative humidity recorded at <500 m asl are 27°C and 74% respectively (CMU, 2012). Areas with elevations >500 m asl have 18-20 °C and relative humidity of ~80%. The areas around the volcanic slopes have semi-temperate conditions which can support broad range of highland crops.

Field Investigation and Soil Sampling

Defined pedons were described according to Delecour and Kindermans (1977). Soil horizon samples were taken for subsequent soil analyses. Undisturbed soil horizons were also taken from each position to measure bulk densities and water retention capacities. A total of 24 representative crop plots were selected for topsoil composite sampling and yield measurements. Twelve plots were situated around P_4 and P_5 and the other 12 around P_7 and P_8. Each studied location had four plots that were planted with potatoes, four with carrots and four with corn were investigated. Composite topsoil samples of 20 cm depth were taken from each plot.

Laboratory Analysis

Soil horizon samples were analyzed to determine the soil classification. Parameters were soil pH (H_2O and 1N KCl), exchangeable acidity and Aluminum (Al) by Yuan Method and atomic absorption measurement for Al, TOC (adapted Springer Klee Method), allophanes (Fieldes and Perrot, 1966), Cation exchange capacity (CEC) and cations (Metson Method with 1 N ammonium acetate at pH7), and total P (tri-acid mineralization). Complementary analyses for sesquioxides were conducted to check the criteria of possible andic, nitic/ferralic characteristics. Water holding capacities and bulk densities were obtained. Topsoil samples were also analyzed to find out the fertility status. Parameters examined were pH (H_2O and 1N KCl), total organic carbon (TOC) (Walkley-Black Method), total nitrogen (TN) (Kjeldahl Method), Carbon and nitrogen (C/N) ratio, available calcium (Ca), magnesium (Mg), Potassium (K) and sodium (Na) (ammonium acetate-0.5N and EDTA+0.02M at pH4.65 followed by atomic absorption measurement) and available Phosphorous (P) (by colorimetry). Mineral P for selected horizons from representative pedons was analyzed by mineralization with H_2SO_4-6N and phosphate retention by the same method as active aluminum (Al) and iron (Fe) (Blakemore method) and was read by colorimetry.

Crop Yield Measurement Procedure

Adopting the procedure from Hauser (1973), crop yields were measured. A rectangular harvest frame was established in a plot in which three-crop rows were enclosed. To delineate the frame dimensions, the formula XY = 10 m^2 was used. X as the reference, is the width of frame which is three times the crop row distance in meters measured on center. Y is the length of the frame in meters and the frame area is 10 m^2. The four corners were marked with metal pegs and the enclosed area was cordoned with a nylon rope. Weights of crop harvest and plant densities within the enclosed area were taken. Three pieces of the harvested root crops (potatoes and carrots) which were chosen randomly were brought to the laboratory for the soil weight correction factor determination. Corn cobs were dehusked, dried and shelled and weights were taken at 12% moisture content at which these were safe for storage (Granados, 2000).

Application of Statistical Methods

By Minitab 16, the Two-Sample T test was used to determine the differences of soil nutrient levels between Salsalan and Mambuaw. Linear correlations test and rank correlations test were applied to detect the associations of soil fertility nutrient levels with crop yields.

Results and Discussion

Morphological Characteristics

There are two main soil types in Miarayon according to the World Reference Base for Soil Resources (FAO, 2006). Soils in open positions such as convex to steep side are Cambisols. Those on concave to flat positions are Umbrisols which were derived from either colluvial or alluvial deposits from volcanic materials. Test for allophanes confirmed the presence of amorphous components in all pedons. Analyses of selected representative samples indicated some "andic" properties. Table 1 presents the soil classification and characteristics of the soil pedons of Salsalan and Mambuaw production locations.

Table 1. Soil classification, position, elevation, slope and land use of soil pedons in production locations of Miarayon, Talakag, Bukidnon.

Location	Soil Pedon	Main Classification	Position	Slope (%)	Elevation (m asl)	Land Use
Salsalan	P_4	"Andic" Umbrisol	Wavy mesorelief, concave in middle part	7	1489	Potatoes, carrots, corn, fallow
	P_5	"Andic" Umbrisol	Wavy mesorelief, concave in middle part	10	1496	Potatoes, carrots, corn, fallow
Mambuaw	P_7	"Andic" Cambisol	Rectilinear crest	4	1363	Potatoes, carrots, corn, fallow
	P_8	"Andic" Cambisol	Divide Convex/ Linear	2	1348	Potatoes, carrots, corn, fallow

Umbrisols have deeply drained, medium textured soils with dark, acid surface horizon, rich in organic matter with a base saturation of <50% in the Umbric horizon (Driessen et al., 2001). Soils in P_4 and P_5 have brownish black topsoil, sandy loam to sandy clay loam texture, pH values of 5.0 and 5.2 at surface horizons, base saturation of 6.2 and 16.1% and with good drainage. Cambisols occur in the stage of early soil development in widely different environment. They are medium-textured and have a good structural stability, high porosity, good water holding capacity and good internal drainage (Driessen et al., 2001). Soils in P_7 and P_8 have sandy clay loam in the top horizon and silty clay loam to silty clay in the sub horizons, have very high to high porosity and with 35.8 and 52.9% field capacity, respectively.

Soil Fertility Assessment

Table 2 presents the topsoil nutrient analyses results in potato, carrot and corn plots. Of the 24 plots investigated, 71% had pH <5.5. No value had exceeded 5.9. Of the 12 plots in Mambuaw, except for one plot, the pH values were <5.5. Soils with pH value <5.5, has high P retention and plants are at risk of Al toxicity (Landon, 1991). Exchangeable Al in the surface horizon of P_7 and P_8 had 1.59 and 1.81 $cmol_+kg^{-1}$ respectively. However, high CEC in P_7 and P_8 (42.0 and 38.9 $cmol_+kg^{-1}$, respectively) would buffer the risk. It was noted that available P was very low (<1mg/100g), thus follow up analyses were made on selected soil horizon samples from representative plots for organic P to get P retention. The P retained as the percentage of organic P in the total P ranged from 60-95%.

Table 2. Topsoil analyses results in potato, carrots and corn plots at 20 cm depth.

Potatoes										
Location	Plot	pH H_2O	TOC	TN	C/N ratio	Ca^{2+}	Mg^{2+}	K^+	Na^+	∑ Bases
Salsalan	SP_1	5.8	8.3	0.75	11	7.88	1.48	0.66	0.09	10.80
	SP_2	5.4	7.8	0.72	11	7.04	0.90	1.18	0.09	9.21
	SP_3	5.4	6.4	0.57	11	3.94	0.49	0.77	0.04	5.24
	SP_4	5.5	7.6	0.68	11	6.74	0.74	0.95	0.13	8.56
Mambuaw	MP_1	5.2	5.9	0.46	13	3.59	0.58	0.41	0.09	4.67
	MP_2	5.1	5.6	0.39	14	2.35	0.82	0.23	0.09	3.49
	MP_3	5.5	7.2	0.50	15	2.74	0.58	0.28	0.04	3.64
	MP_4	5.1	5.0	0.39	13	3.09	0.49	0.61	0.09	4.28
Carrots										
Location	Plot	pH H_2O	TOC	TN	C/N ratio	Ca^{2+}	Mg^{2+}	K^+	Na^+	∑ Bases
Salsalan	SC_1	5.4	7.5	0.6	12	4.44	0.33	0.95	0.04	5.76
	SC_2	5.4	6.5	0.6	11	3.79	0.25	0.87	0.04	4.95
	SC_3	5.9	8.4	0.8	11	9.78	0.66	1.00	0.09	11.53
	SC_4	5.1	7.2	0.6	11	2.15	0.16	0.54	0.13	2.98
Mambuaw	MC_1	5.4	4.1	0.3	14	2.10	0.16	0.31	0.04	2.61
	MC_2	5.4	7.0	0.5	15	2.40	0.25	0.20	0.04	2.89
	MC_3	5.1	8.7	0.6	15	2.64	0.16	0.28	0.09	3.17
	MC_4	5.3	6.5	0.4	14	2.50	0.16	0.23	0.09	2.98
Corn										
Location	Plot	pH H_2O	TOC	TN	C/N ratio	Ca^{2+}	Mg^{2+}	K^+	Na^+	∑ Bases
Salsalan	SCo_1	5.8	6.7	0.75	11	7.84	0.74	1.13	0.04	9.45
	SCo_2	5.8	8.4	0.72	11	7.39	1.15	0.59	0.04	9.17
	SCo_3	5.4	8.9	0.57	11	2.30	0.25	0.43	0.09	3.07
	SCo_4	5.8	5.9	0.68	8	4.95	0.74	1.05	0.09	6.83
Mambuaw	MCo_1	5.0	5.2	0.46	13	1.95	0.41	0.49	0.04	2.89
	MCo_2	5.2	5.0	0.39	14	1.90	0.41	0.38	0.09	2.78
	MCo_3	5.0	6.8	0.50	15	2.60	0.49	0.43	0.04	2.56
	MCo_4	5.1	5.8	0.39	13	11.24	2.14	1.07	0.04	14.49

Unit: TOC (%), TN (%), Bases ($cmol_+kg^{-1}$)

Miarayon farmers primarily use chicken manures which were mixed with rice hulls as fertilizers before planting and therefore are external sources of TOC and part of TN. TOC contents was medium and TN values are medium to high. C/N ratio indicates the degree of organic humification and thus higher values imply abundance of less decomposed crop residues. C/N ratios in Salsalan indicated higher degree of humification than in Mambuaw.

The predominance of Ca in both locations can be attributed to the parent rock of Miarayon soils. Chicken manure applications can be possible external source of Ca because poultry feed formulas have Ca such as mono dicalcium phosphate, limestone, oyster shells and other Ca-source ingredients. Low Ca values and response of Ca fertilizer in most crops is when the level is <0.2 $cmol_+kg^{-1}$ and the high value is about 10 $cmol_+kg^{-1}$ (Landon, 1991). Of the 24 plots, none of its Ca had gone to the low level and 50% of these were above of what is considered high. High Ca availability in soil can be explained by its affinity with exchange complexes of soil organic matter (SOM), allophanes, kaolinite and oxides of Fe and Al (Camberato and Pan, 2000) which were also found in Miarayon soils. Magnesium deficiency occurs when its exchangeable level is <0.2 $cmol_+kg^{-1}$ but in the tropics 0.5 $cmol_+kg^{-1}$ is the threshold (Landon, 1991). Forty five per cent of the total samples were above the limit, 38% were on the threshold and 17% were below the limit. Compared to Ca, the low Mg availability can be attributed to the nutrient's less affinity to soil exchange complexes than Ca (Camberato and Pan, 2000) in Miarayon soils making this nutrient susceptible to leaching. Less absorption of Mg may also occur because of high Ca levels in the soil. If Ca/Mg ratios >5, Mg may progressively be unavailable (Landon, 1991). Of the 24 samples analyzed, 83% had ratios >5. Available K of 0.20-1.18 $cmol_+kg^{-1}$ in Miarayon soils is considered medium to high for tropical soils. CEC enables soil to retain K and the amount of clay and SOM influence the degree of leaching (Sparks, 2000). Miarayon soils have high CEC and SOM. Mg uptake can also be affected by K in soils. At K/Mg ratios >2, Mg uptake is inhibited and only three plots are at this ratio which were all planted with carrots in Salsalan.

Soil Fertility Levels Between Salsalan and Mambuaw

Table 3 shows the differences in soil fertility levels between the two production locations. Because of the time-length difference in using the land, it was assumed that both locations have different states of soil fertility.

Table 3. Differences in soil fertility levels between Salsalan and Mambuaw using Two-Sample T Test.

Parameter	P Value	Parameter	P Value
pH water	0.023*	Ca^{2+} ($cmol_+kg^{-1}$)	0.013*
TOC	0.003***	Mg^{2+} ($cmol_+kg^{-1}$)	0.300^{ns}
TN	0.000***	K^+ ($cmol_+kg^{-1}$)	0.000**
C/N ratio	0.000***	Na^+ ($cmol_+kg^{-1}$)	0.178^{ns}
		Sum of Bases ($cmol_+kg^{-1}$)	0.013*

Note: ***very highly significant ($P \leq 0.001$) **highly significant ($P \leq 0.01$) *significant ($P \leq 0.05$)
^{ns} not significant ($P > 0.05$)

The differences in TOC, TN and K between two locations were very highly significant, and in pH and Ca were significant. Soil fertility in Salsalan is better than in Mambuaw. Results suggested that TOC, TN and K were severely affected by long and continuous cultivation. Continuous cropping is a slow process of soil nutrient mining which will exhaust the soil's capacity to support plants. Less or no replenishment of nutrients can deplete the soil fertility in the long run. Miarayon soils which are derived from volcanic parent materials are acidic. There is significant difference between the pH values of the two locations. The presence of humus-Al and Fe complexes with layer silicates in clay lowers the soil pH (<5) because under humid conditions cations that are liberated during the weathering process are washed out from the soil while Al and Fe are bound in humus (Mizota and van Reeuwijk, 1989). Topsoils in Mambuaw has relatively low pH (<5) and in this location high amounts of exchangeable Al in soil were detected.

Available Ca was significantly higher in Salsalan than in Mambuaw. This may mean that Ca leaching or washing out is lesser in Salsalan than in Mambuaw. Like Ca, there is significant difference in pH between the two locations because Ca influences the soil pH (Bear and Toth, 1948). The variation of available Mg were not detected which could mean that this nutrient is not affected by cultivation duration. The non-significant difference in available Na between the two sites may be due to the nutrient's low amounts.

Crop Yields and Plant Densities

Crop plot sizes of vegetable production areas in Miarayon do not exceed half a hectare. The plot modal class size of potatoes was from 250-750 m^2 with smallest area of 60 m^2 and the largest was 3,644 m^2. Carrot areas modal class size was from 1,250-1,750 m^2 with smallest area of 409 m^2 and the largest, 4,178 m^2. For corn, the plot modal class size was from 500-1,500 m^2 with the smallest area of 127 m^2 and the largest was 6,386 m^2. Supply of potatoes in Northern Mindanao comes from Bukidnon and majority is produced in Miarayon. Carrot production significantly contributes to the national volume as Bukidnon ranks fifth in the Philippines

(BAS, 2013). Farmers in Miarayon raise the native corn for food. Corn is in rotation with potatoes and carrots which does not include application of fertilizers for maintenance.

Table 4 shows the crop yields of potatoes, carrot and corn. Farmers in Miarayon practice direct seeding when planting carrots and corn. For carrots, thinning comes after one month to control the plant population. The table further shows the plant densities of carrots and corn in the plot. Carrot plant densities were obtained by counting the individual tap root and for corn, the individual stalk inside the harvest frame.

Table 4. Crop yields and plant densities.

Crop	Location	Plot	Yield*	Mean Yield*	Yield Difference*	Plant Density*
Potato	Salsalan	SP_1	29.09	28.99	8.98 (31.0%)	
		SP_2	30.11			
		SP_3	27.00			
		SP_4	29.77			
	Mambuaw	MP_1	18.65	20.01		
		MP_2	19.91			
		MP_3	23.24			
		MP_4	18.24			
Carrot	Salsalan	SC_1	36.78	18.41	-2.39 (-13.0%)	238
		SC_2	8.02			104
		SC_3	18.51			279
		SC_4	10.32			86
	Mambuaw	MC_1	18.19	20.80		198
		MC_2	19.66			288
		MC_3	24.15			288
		MC_4	21.02			214
Corn	Salsalan	SCo_1	3.68	3.75	0.29 (8.4%)	48
		SCo_2	4.47			51
		SCo_3	3.03			43
		SCo_4	3.82			50
	Mambuaw	MCo_1	2.77	3.46		37
		MCo_2	2.14			29
		MCo_3	3.58			48
		MCo_4	5.34			59

*Units: Yield and Mean Yield (tha^{-1}), Yield Difference (tha^{-1} and %), Plant Density (plants/10 m^2)

Mean yield of potatoes in Salsalan is higher than in Mambuaw. Potato yields in Salsalan were comparable to the Miarayon region yields 13 years ago. Potato adaptation trial results by Tatoy et al. (2001) in Miarayon, Lirongan and San Miguel had yields of 26.16, 23.19 and 25.63 tha^{-1} respectively. Mean carrot yield in Salsalan is less than in Mambuaw by 2.35 tha^{-1}. Mean yields in two locations were higher than the 2012 Bukidnon Province carrot average yield which was 10.72 tha^{-1} (BAS, 2013). Mean yield of corn does not differ significantly in both production areas. Miarayon yield was almost twice as much as the 2012 Bukidnon white corn yield of 1.88 tha^{-1} (BAS, 2013) although farmers do not apply fertilizers to corn plots. Corn cropping that do not use fertilizer follows potato or carrot production. Corn may have benefited the slow release of nutrients applied in the previous cropping.

Calibration of Crop Yields with Soil Fertility Levels

Table 5 shows the statistical analysis results for yields with soil nutrient levels. Potato yields were highly correlated with TOC, TN, available Ca, K and fairly associated with pH H_2O. There is inverse relationship between potato yield and C/N ratio. In this study, there was no association detected between potato yield and Mg availability although the nutrient is important to the crop. This could mean that available Mg is not affected by potato cultivation. There is no relationship between potato yields and Na because of its low quantity and Na is not a critical element for any crop unless its concentration in soil is beyond crop tolerance.

Table 5. Correlation results for crop yields and soil nutrients.

Crop	Value	pH H_2O	TOC	TN	C/N Ratio	Ca^{2+}	Mg^{2+}	K^+	Na^+
Potato	R	0.784	0.887	0.950	-0.753	0.849	0.515	0.761	0.176
	P	0.021*	0.003**	0.000***	0.031*	0.008**	0.192^{ns}	0.028*	0.676^{ns}
Carrots	R	0.047	0.253	0.042	0.323	0.095	0.130	0.066	-0.297
	P	0.400^{ns}	0.545^{ns}	0.921^{ns}	0.435^{ns}	0.823^{ns}	0.758^{ns}	0.876^{ns}	0.476^{ns}
Corn	R	0.173	0.222	0.274	-0.184	0.896	0.894	0.755	-0394
	P	0.682^{ns}	0.598^{ns}	0.512^{ns}	0.663^{ns}	0.003**	0.003**	0.031*	0.259^{ns}

***very highly significant ($P \leq 0.001$),**highly significant ($P<0.01$), *significant ($P \leq 0.05$), ^{ns}not significant ($P>0.05$)

At this level of investigation, there was no relationship detected between carrot yields and soil nutrients, yet some observations were drawn from crop behavior in response to topsoil quality. Optimum pH requirement for carrots is 6.0 (Rubatzky, 1999) and all carrot plots fell below the condition. However, carrot yields in these areas were higher than the Bukidnon values. In Mambuaw, the plot with the highest carrot yield (MC_3) also had the highest TOC (8.7%), TN (0.6%) and sum of available bases (3.17 $cmol_+kg^{-1}$). The plot with the lowest yield (MC_1) has also the lowest TOC (4.1%), TN (0.3%) and sum of available bases (2.61 $cmol_+kg^{-1}$). For Salsalan, the plots with low yields had K/Mg ratio of >2 (SC_2, 3.5:1 and SC_4, 3.4:1) in which at this values may inhibit the uptake of Mg (Landon, 1991). Moreover, according to the plot owners these were affected by long dry days during their early stage of planting. Miarayon crops are rain-fed. Carrots like a uniform supply of water throughout the growing season (Fritz et al., 2013) and hot sunny days can injure or kill the young plants. Plant densities of these two plots were 104 and 84 plants per 10 m^2 only which were less than half of the average modal carrot plant densities. The plot with the highest yield value was that the crop was harvested the latest although its K/Mg ratio is 2.9. In Miarayon, the schedule of harvest is dictated by the plot financiers who watch the commodity market trends. Plant density shows that the sizes of the carrots in this plot were much bigger than the average tubers. Compared to the three groups of crop plots, carrot plots had low available Mg. Soil tests <50 ppm (<0.41 $cmol_+kg^{-1}$) are considered low (Fritz et al., 2013).

Corn yields had high correlation with available Ca, Mg and K. One can assume that corn apparently responds to different levels of available bases. In this study, there was no sign of linkage with the rest of the soil nutrients. The K/Mg ratio had ranged from 0.5 to 1.7 which were below the limit of >2. Therefore, Mg uptake may not be severely affected by the presence of K in soils. The pH requirement for corn ranges from 5.0-8.0, with optimal values of 6.0-7.0, and N is the most important nutrient (Landon, 1991). Although pH values of Miarayon soils fell into the low boundary, corn grows well because of the high TN in soils.

Conclusion

Miarayon soils can still be considered as fertile however, the long periods of cultivation had depleted the basic nutrients in topsoil. Low soil pH in the old settlement would pose the risk of Al toxicity. However, momentarily this is cushioned by high CEC which is inherent in soils derived from volcanic parent materials although the base saturation ratios were low. Available Ca was influential in the soil pH. In this study, the differences of Mg and Na levels between the two locations were not significant. TOC, TN, C/N ratio and K may drastically be affected by long cultivation unless soil improvements are made. Yield of potatoes, carrots and corn are higher than the recent provincial average yield values. Soil pH, TOC, TN, C/N ratio, available Ca, K can be useful to estimate the yield of potatoes. In this investigation, there is obscurity in using soil nutrients as indicators for carrot yield. Corn yield can be predicted at certain levels of available Ca, Mg and K. Established SRS is baseline information that can be useful for Miarayon farmers in assessing the soil fertility. Crop yield data may enable Miarayon farmers to estimate the plot production capacity at given soil nutrient levels. The methodology that was developed can be replicated in other highland areas of Mindanao. This can serve as model to be adopted by highland farming communities in generating soil information at the local level.

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