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Influence of Long-term Cultivation on Soil Nutrient Status and Properties of Paddy Fields in Panitan, Capiz, Philippines

Jinky D. Dogello[1] and Deejay Maranguit-Lumanao[2]

ABSTRACT

Soil fertility evaluation of long-term cultivated paddy fields is relevant for proper nutrient assessment and adequate fertility management. Thus, the study was conducted to evaluate the physicochemical and biological properties, as well as determine the nutrient status, and recommend proper nutrient management practices in selected barangays of Panitan, Capiz, Philippines. Soil samples were collected from six farms and analyzed for their morpho-physical, chemical, biological properties and fertility status. Results revealed that the soil of all farms are slightly to moderately developed having an Ap, AB, Bg, Btg, Bwg, BC, and C horizons. They have brown-colored horizons, which have clay texture, few to no rock fragments, sub-angular blocky soil structure, friable, slightly sticky and slightly plastic, and coarse to fine mottles. The highest soil microbial activity was noted seven days after incubation. Results also revealed that all soils studied are less fertile having a very strongly acidic to slightly alkaline soil pH (4.83 to 7.47), very low to a low amount of soil organic matter (0.15% to 2.81%), very low to medium total nitrogen (0.03% to 0.22%), low to moderate available phosphorus (0.1 mg kg^{-1} to 17.31 mg kg^{-1}), low to moderate exchangeable potassium (0.06 cmol kg^{-1} to 0.7 cmol kg^{-1}), and very low to low cation exchange capacity (0.027 cmol kg^{-1} to 12.68 cmol kg^{-1}). Therefore, to enhance the fertility status of the paddy fields it is recommended to integrate the rice straw after harvest, practice green manuring, and combine organic and inorganic fertilizer applications.

Keywords: Alimodian, long-term cultivation, nutrient status, paddy field, soil fertility

INTRODUCTION

Paddy cultivation significantly plays an important role in rice production (Watanabe 2018). The majority of East and Southeast Asian countries, as well as the other half of the global population, are fully dependent on rice as their staple food (Ferrero & Tinarelli 2008). However, long-term monoculture of rice results in

[1]Department of Soil Science, Visayas State University, Visca, Baybay City, Leyte
[2]Assistant Professor II, Department of Soil Science, Visayas State University, Visca, Baybay City, Leyte

*****Corresponding Author:** Deejay Maranguit-Lumanao **Address:** Visayas State University, Visca, Baybay City, Leyte
E-mail: deejay.maranguit@vsu.edu.ph

yield reduction due to continuous nutrient mining which negatively affects the physical, chemical, and microbiological composition of the soil (Edwards et al 2019). Thus, proper cultivation management and dosage of fertilizer applications are necessary to enhance rice productivity and maintain soil quality in paddy fields.

Panitan is a third-class municipality in the province of Capiz (Mapcarta 2022). Capiz, where the municipality of Panitan belongs, ranked fourth in Palay production in Region VI (Western Visayas) in 2019 contributing 14.52% of the total production of the region. As recorded, the palay production in Capiz had decreased from 348.48 thousand metric tons (MT) in 2017 to 301.77 MT in 2019 (PSA 2020).

At present, information regarding soil physical, chemical, and biological properties of paddy fields in Panitan, Capiz is still lacking. Also, there is no detailed characterization of the soil nutrient status and the effect of long-term rice cultivation in Panitan. Thus, the study was conducted to evaluate the current nutrient status and characterize the physical, chemical, and biological properties of the soil in the paddy fields of Panitan Capiz to recommend appropriate nutrient management for the increase in the overall growth and yield performances of rice in the locality and to reduce soil fertility constraints.

MATERIALS AND METHODS

Site Selection and Description

The study was conducted in the Municipality of Panitan, Capiz (Figure 1), in the paddy fields of six (6) selected barangays, such as Brgy. Cabangahan, Cabugao, Ambilay, Pasugue, Cadio, and Calaan. In every barangay, one (1) farm owner was interviewed using a structured questionnaire. For detailed characterization, a soil profile per barangay was prepared from a field that has been cultivated for paddy rice production for 5 years or more. The chosen paddy field per barangay was further subdivided into three (3) equal parts where composited soil samples were collected at 0-20cm depth. The selected barangays are within the alluvial plains with Alimodian clays as their Soil Series identified by PhilRice (2013). The biophysical features of the site which are the parent material, land use, drainage, climate, vegetation, topographic position, and landform were characterized following the FAO Guidelines for Soil Description (Jahn et al 2006).

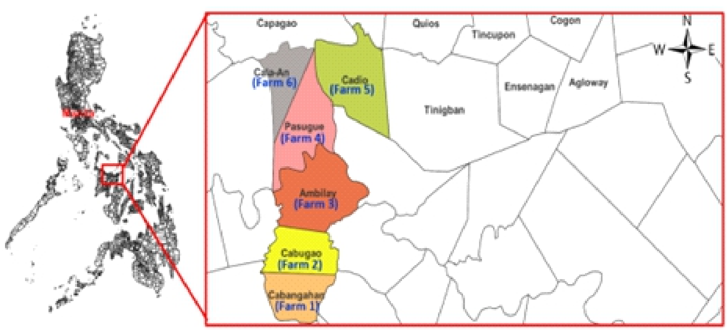


Figure 1. Location of the study sites in Panitan, Capiz, Philippines (Source QGIS)

Laboratory Analysis

Bulk density was analyzed using the core method (ISRIC 2002) and percent (%) porosity was calculated from the bulk density value and a constant particle density of 2.65 g/cm3. Particle size distribution was determined using Hydrometer method (ISRIC 1995). Water holding capacity was determined through gravimetric method (Wilke 2005). Soil pH was analyzed using potentiometric method (ISRIC 2002). Soil organic matter was analyzed through Modified Walkley and Black (Spectrophotometric) Method (PCARR 1980). Total N was analyzed through Micro-Kjehldahl method (Jackson 1958). Available P was analyzed through Bray 2 Method and Olsen Method of BSWM (2014). Exchangeable K was extracted using the 1N NH4OAc (pH 7.0) method (PCARR 1980). Exchangeable Al was determined through KCl -NaF Titration Method (BSWM 2014). CEC was also evaluated using Ammonium Acetate Method (USDA – NRCS 1996). The surface samples were analyzed for bulk density, porosity, water-holding capacity, Total nitrogen, Available phosphorus, Exchangeable potassium, and microbial activity (Page 1982), while profile soil samples were evaluated for particle size distribution, water-holding capacity, Total N, Available P, Exchangeable K, Exchangeable Aluminum, cation exchange capacity.

RESULTS AND DISCUSSION

Soil Morphological Characteristics

The morphological classification of soil plays a vital role in determining the shift, development, or transformations in a given soil body. This can be determined through a thorough description of a soil profile and an evaluation of its properties by examining its horizons depth, boundary, color when moist, texture, rock fragments, structure, wet and dry consistency, as well as, the presence of roots, and mottles. In Table 1, the morphological properties of paddy fields in selected farms of Panitan, Capiz were shown.

It was found that Ap, AB, Btg1, Btg2, and Btg3 are the dominant horizons among the six soil profiles, as in the case of Farms 2 and 3. However, illuvial accumulation of silicate clays is absent in Farm 1, where subsurface horizon (B) with a stagnic (g) condition (Jahn et al 2006) was only noted. Aside from Ap and Btg horizons, Farm 4 has a Bwg horizon, Farm 5 has BC and C horizons, while Farm 6 has Bwg, BC, and C horizons. Ap horizon is a surface mineral horizon frequently disturbed by anthropogenic activities like plowing as a part of land preparation in arable land. On the other hand, Btg horizons is a mineral subsurface horizon rich in illuvial silica (t) deposition and have a stagnic prevailing soil condition (g). For BC, this is a transition horizon where the soil has a characteristic of both B and C horizons. However, unconsolidated parent materials or saprolite can be found in the C horizon. Here, minimal soil formation occurs as pedogenic processes are relatively low in this horizon compared to the A and B horizons (Canadian Society of Soil Science 2020).

The color of the soil profile in Farm 1 ranges from very dark grayish brown (10 YR 3/2) to dark brown (10 YR 3/3) from the surface down to the Btg3 Horizon. For Farm 2, strong brown color (7.5 YR 4/6) can be seen on the surface with light-yellowish brown (10 YR 6/4) to brownish yellow (10 YR 6/6) in the subsurface horizon. One notable characteristic of Farm 2 is its red (10 R 4/6) mottles in the Btg1 horizon. For Farm 3, the color of the horizon ranges from dark-yellowish brown (10 YR 3/6) to yellowish brown from the surface down to the subsurface Btg3 horizon. In Farm 4, the color of the surface horizon is dark brown (10 YR 3/3), while the underlying subsurface (AB, Bwg, Btg1, and Btg2) is dark yellowish brown (10 YR 3/4 and 10 YR 4/4). Among all the soil profiles, Farm 5 has a unique color: dark red (10 R 3/6, 2.5 YR 3/6, and 2.5 YR 3/8) in the Ap, BC, and C horizons, while red (10R 4/6) in the middle Btg1 and Btg2 horizons. Also, it has pale brown (2.5 Y 7/3) to very pale brown (10 YR 7/3) mottles from the topmost Ap horizon down to the lower Btg1, Btg2, and BC horizons. Lastly, Farm 6 has a very dark grayish brown (10 YR 3/2) color of the Ap and Btg soil horizons to dark yellowish brown (10YR 4/4) and pale brown (10 YR 6/3) BC and C horizons. The letters YR refers to the hue color yellow-red, while R is red (Zhang et al 2021).

When moist, all of the horizons in soil profiles of six farms were found to have a friable consistency since it crumbles and forms aggregates with light applied pressure (Cornell University 2010). A friable soil favors most of the underground activity like the promotion of root growth, uniform development of storage roots for most root crops, and efficient drainage (Beaulieu 2019). A friable soil is commonly rich in carbon and minerals which is ideal for growing most crops (Farming Base 2022). When wet, sst (slightly sticky) and spl (slightly plastic) were the dominant characteristics in the Ap horizon of the soil profiles in six farms; Bg1, Bg2, and Bg3 horizons of Farm 1; AB horizon of Farms 2, 3, and 4, BC and C horizons of Farm 5 and 6; and Bwg horizon of Farm 6. However, in the Btg horizons (in the case of Farms 3, 4, 5, and 6) where the illuvial accumulation of clay is dominant, the most common soil consistency obtained is sticky (st) and plastic (pl).

In terms of soil structure, a weak (1), fine (f) to medium (m) sub-angular blocky (sbk) or 1fsbk and 1msbk are dominant in the Ap horizon of the six soil profiles, AB horizon of Farm 3, and Bwg horizon of Farm 6. A weak soil structure is formed from indistinct soil aggregates that tend to disintegrate into very few entire aggregates, more broken aggregates, and quite many unaggregated materials when removed from the soil profile. In contrast, moderately structured soil is considered well-formed and is developed from distinct aggregates that are durable and evident, however, non-distinct in undisturbed soil. Compared to weakly aggregated soil, its materials when broken down during removal from the soil profile are made up of mixed distinct entire aggregates, partly broken aggregates, and a minute amount of unaggregated materials (FAO nd). For the AB horizon of Farms 2 and 4, as well as for the Bg1, Bg2, Bg3, Bwg, Btg1, Btg2, Btg3, BC, and C horizons of the six farms, the structure ranges from moderate (2) fine (f) sub-angular blocky (sbk) or 2fsbk to moderate (2) medium (m) subangular blocky or 2msbk. The moderate formation of sub-angular blocky structures is commonly influenced by the presence of clay. Normally, as clay accumulation is the dominant characteristic to be classified as B horizon, the formation of moderately sub-angular blocky soil aggregates is evident (FAO nd).

The depth, size, and amount of roots present are highly variable in all soil profiles of the six farms studied. In Farm 1, roots can only be found common (cm) on the Ap horizon, few fine (fefi) in Bg1, and very few fine (vfefi) in Bg2. In Farm 2, it is only present in the Ap (cm) and AB (fefi) horizons. However, in Farm 3, it is observed

Ap (cm), Btg1 (fefi), Btg2 (vfefi), and AB horizons where it is common fine (cfi). In Farm 4, it is concentrated mainly in the Ap (cm), AB (fefi), and Bwg (vfefi). In Farm 5, it is only present in Btg1 (fefi) and a few medium (fem) in Ap. In Farm 6, plant roots are only limited to Ap (cm), Btg (cfi), and Bwg (vfefi) soil horizons. The mottles of different soil profiles in six farms are described based on abundance (f-few, c-common, m-many), size (1-fine, 2-medium, 3-coarse), and contrast (f-faint, d-distinct, p-prominent, o-none). It was found that no mottles (o) have been noted in the Ap horizon of all soil profiles studied. Mottles were also absent in all soil horizons of Farm 1. For Farm 2, it is only concentrated in c2p in AB horizon, m2d in Btg1 and Btg2, and m3d in Btg3. However, in Farm 3, it was found f1f in AB and Btg3, and f2d in Btg1 and Btg2. In Farm 4, mottles were notable in f1f from AB down to Btg2. In Farm 5, it is found in m1p in Btg1, m2p in Btg2 and BC, and m3p in C. lastly, mottles were only found in f1f in Btg and Bwg, c1d in BC, and c2d in C horizons of the soil profile in Farm 6.

Table 1. Morphological properties of paddy fields in selected farms of Panitan, Capiz, Philippines

HORIZON[A]	DEPTH (CM)	BOUNDARY[B]	COLOR (MOIST)	TEXTURE[C]	ROCK FRAGMENTS[D]	STRUCTURE[E]	CONSISTENCE[F]		ROOTS[G]	MOTTLES[H]
							moist	wet		
Farm 1 (Brgy. Cabangahan – Soil Profile 1)										
Ap	0-27	Cw	10YR 3/2 (Very dark grayish brown)	C	n	1msbk	fr	sst&spl	fefi	o
Bg1	7-42	Cs	10 R 3/3 (Dark brown)	C	n	2fsbk	fr	sst&spl	vfevfi	o
Bg2	42-61	Ds	10YR 3/3 (Dark brown)	C	n	2msbk	fr	sst&spl	n	f1f
Bg3	61-100	Ds	10YR 3/3 (Dark brown))	CL	n	2msbk	fr	sst&spl	n	f1f
Farm 2(Brgy. Cabugao – Soil Profile 2)										
Ap	0-19	Cw	7.5YR 4/6 (Strong brown)	C	n	1msbk	fr	sst&spl	cm	o
AB	19-33	Ds	7.5YR 5/6 (Strong brown)	C	n	2msbk	fr	sst&spl	fefi	c2p
Btg1	33-53	Ds	10YR 6/4(Light yellowish brown), Mottles – 10R 4/6 (Red)	C	n	2fsbk	fr	st&pl	n	m2d
Btg2	53-70	Ds	10YR 6/4 (Light yellowish brown)	C	n	2msbk	fr	st&pl	n	m2d
Btg3	70-100	Di	10YR 6/6 (Brownish yellow)	C	vf	2msbk	fr	st&pl	n	m2d
Farm 3 (Brgy. Ambilay – Soil Profile 3)										
Ap	0-16	Cs	10YR 3/6 (Dark brown)	C	n	1msbk	fr	sst&spl	cm	o
AB	16-25	Cs	10YR 4/3 (Brown)	C	n	1msbk	fr	sst&spl	cfi	f1f
Btg1	25-42	Ds	10YR 5/4(Yellowish brown)	C	n	2fsbk	fr	st&pl	fefi	f2d
Btg2	42-71	Ds	10YR 5/4(Yellowish brown)	C	n	2msbk	fr	st&pl	vfefi	f2d
Btg3	71-100	Di	10YR 5/4(Yellowish brown)	C	n	2msbk	fr	st&pl	n	f1f
Farm 4 (Brgy. Pasugue – Soil Profile 4)										
Ap	0-13	Cs	10YR 3/3 (Dark brown)	C	n	1msbk	fr	sst&spl	cm	o
AB	13-25	Ds	10YR 3/4 (Dark yellowish brown)	C	n	2fsbk	fr	sst&spl	cfevfi	f1f
Bwg	25-39	Ds	10YR 3/4 (Dark yellowish brown)	C	n	2fsbk	fr	st&pl	n	f1f
Btg1	39-59	Ds	10YR 4/4 (Dark yellowish brown)	C	n	2msbk	fr	st&pl	n	f1f
Btg2	59-100	Di	10YR 4/4 (Dark yellowish brown)	C	n	2msbk	fr	st&pl	n	f1f

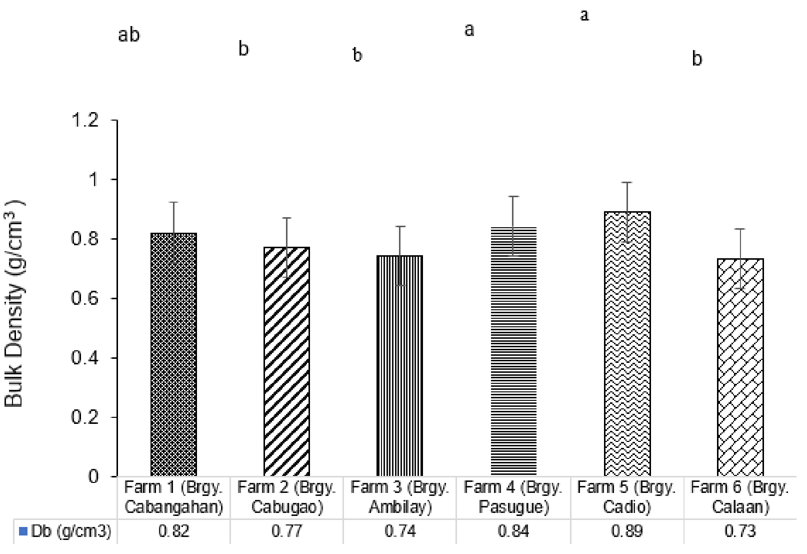
Table 1 continued ..

HORIZON[A]	DEPTH (CM)	BOUNDARY[B]	COLOR (MOIST)	TEXTURE[C]	ROCK FRAGMENTS[D]	STRUCTURE[E]	CONSISTENCE[F]		ROOTS[G]	MOTTLES[H]
							moist	wet		
Farm 5 (Brgy. Cadio – Soil Profile 5)										
Ap	0-14	Cs	10R 3/6 (dark red), mottles - 2.5 Y 7/3 (pale brown)	C	n	1msbk	fr	sst&spl	fem	o
Btg1	14-37	Ds	10R 4/6 (red), mottles - 10 YR 7/3 (very pale brown)	C	n	2fsbk	fr	st&pl	fefi	f1f
Btg2	37-64	Ds	10R 4/6 (red), mottles - 10YR 8/3 (very pale brown)	C	n	2msbk	fr	st&pl	n	f1f
BC	64-78	Ds	2.5YR 3/6 (dark red), mottles 10 YR 7/3 (very pale brown)	SCL	vf	2msbk	fr	sst&spl	n	c1d
C	78-100	Di	2.5 YR 3/8 (dark red)	SCL	fe	2msbk	fr	sst&spl	n	c2d
Farm 6 (Brgy. Calaan – Soil Profile 6)										
Ap	0-14	Cs	10YR 3/2 (Very dark grayish brown)	C	n	1msbk	fr	sst&spl	cm	o
Btg	14-31	Cs	10YR 3/2 (Very dark grayish brown)	C	vf	1msbk	fr	sst&spl	cfi	m1p
Bwg	31-54	Ds	10YR 3/3 (Dark brown)	C	c	2fsbk	fr	st&pl	vfevfi	m2p
BC	54-70	Di	10YR 4/4 (Dark yellowish brown)	C	c	2msbk	fr	sst&spl	n	m2p
C	70-100	Di	10YR 6/3(Pale brown)	SC	c	2msbk	fr	sst&spl	n	m3p

Based on Food and Agriculture Organization (FAO's) Guidelines for Soil Description (Jahn et al., 2006)
A.ai- abrupt-irregular, ci- clear-irregular, cw- clear-wavy, cs- clear-smooth, cd- clear diffuse, gs- gradual-smooth, ds- diffuse-smooth, di – diffuse –irregular
B.C, Clay; L, Loam; CL, Clay Loam; SC, Sandy Clay; SL, Sandy Loam; SCL, Sandy Clay Loam
C.n, no rock fragments; vf: very few, fe; few; c, common
D.1, weak; 2, moderate; f, fine; m, medium; sbk, sub-angular blocky
E.fr, friable; fi, firm; vfi, very firm; sst, slightly sticky; spl, slightly plastic; pl, plastic, st, sticky
F.fem, few medium; cm, common medium; cfi, common fine; fefi, few fine; vfefi, very few fine; fevfi, few very fine; vfevfi, very few very fine; n, none
G. Abundance: f,few, c,common, m,many; Size: 1, fine; 2,medium; 3, coarse; Contrast: f,faint; d, distinct; p, prominent; o-none

Soil Physical Properties

Results revealed (Figure 2) that the bulk density of selected farms range from 0.73 g/cm^3 to 0.89 g/cm^3. The highest significant value was obtained from Farm 5 (0.89 g/cm^3), which is comparable to Farm 1 (0.82 g/cm^3) and Farm 4 (0.82 g/cm^3). These farms have been cultivated for paddy rice for 70 years, 90 years, and 100 years respectively. In addition, the values obtained from Farms 2 (0.77), 3 (0.74), and 6 (0.73) were also comparable to that of Farms 1 and 4. Both Farms 2 and 6 were cultivated for paddy rice for 80 years, while Farm 3 was for 40 years. These values were lesser compared to the range concluded by Wissing et al (2010) which is from 0.9 to 1.3 g/cm^3 in the puddled layer.



Means with the same letter are not significantly different.

Figure 2. Bulk density of paddy soils in selected farms of Panitan, Capiz, Philippines at 0-20cm soil depth

Although long-term cultivated, management practice like puddling and green manuring in paddy soil helps in reducing soil bulk density. Puddling, a wetland rice cultivation, is done by tilling paddy soils with a saturated or near-saturated soil condition (Kirchhof et al 2011). This loosens and softens the soil as it destroys the aggregates, increases porosity, and produces an open structure. As puddling is increased, bulk density decreases (Mohanty et al 2004; Sharma and De Datta 1985, Rezaei 2012) in the puddled zone. While increasing the soil organic matter enhanced the macro and mesopores by 28% due to aggregate stabilization (Sultani et al 2007).

Since the bulk density previously determined was relatively lower, its porosity (Figure 3) increases indicating that the selected paddy fields have porous soils. This result can be correlated to the soil texture of the selected paddy soils is clay. Clay soils have very minute particles with very small pore spaces, making their total porosity greater than sandy soils (Howell 2013).

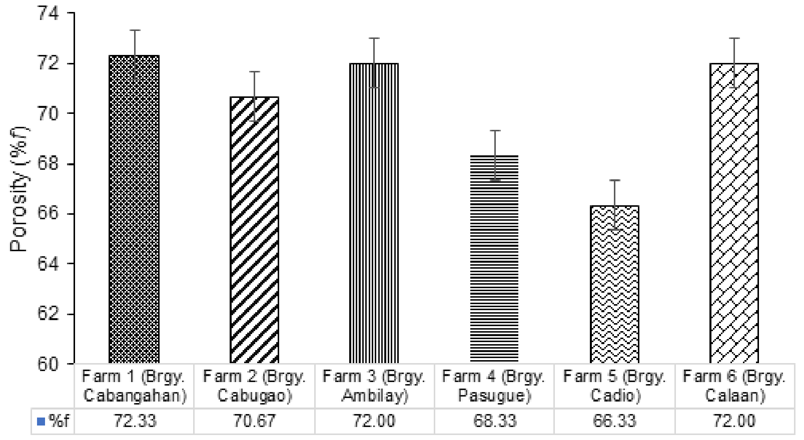


Figure 3. Porosity (*%f*) of paddy soils in selected farms in Panitan, Capiz, Philippines at 0-20cm soil depth

Most of the soil horizons of the six profiles were dominated by clay (Table 2). Wherein, all the soil horizons in Farms 1, 2, 3, and 4 have a clay soil texture, with sand, silt, and clay fractions ranging from 19% to 40%, 7% to 33%, and 39% to 70%, respectively. Clay textured soils were dominant in the area since the data from PhilRice (2013) have found that the soil from the Municipality of Panitan, Capiz, has developed from Alimodian clay which is its Soil Series. Alimodian soil is formed from soft, porous, and fine-textured soils (like sandstones and mudstones) with a greater fraction of clay that usually ranges from 35% to 65%. This old soil has a notable accumulation of illuvial clay in the subsurface horizons. However, in the case of Farms 5 and 6, sandy clay loam and sandy clay textured horizons have occurred respectively since the occurrence of BC and C horizons of both soil profiles have contributed to an increase of the sand and silt fractions of the soil since this is where the unconsolidated parent materials take place.

Results revealed that the maximum water-holding capacity of soil profiles Table 2) was obtained from the uppermost 0-20 cm soil depth of the profile, where the mean values ranged from 46.39% to 79.03%. This occurs as organic matter concentration is greater at this soil depth. The organic matter which is intimately mixed with mineral soil materials has a considerable influence in enhancing the soil water holding capacity either by increasing the number of micropores and macropore, or create an optimum environment for microbial activity. Reicosky (2005) found that there are types of organic matter that can hold moisture up to 20 times their weight. Also, Hudson (1994) concluded that the water-holding capacity of soil is increased by 3.7% for every 1% increase in organic matter.

Table 2. Physical characteristics of soil profiles of selected Farms in Panitan, Capiz, Philippines

SOIL HORIZON	SOIL DEPTH (cm)	PARTICLE SIZE DISTRIBUTION (%)			TEXTURAL CLASS	WHC (%)
		SAND	SILT	CLAY		
Farm 1 (Soil Profile 1 -Brgy. Cabangahan)						
Ap	0-27	26.00	33.00	41.00	Clay	56.58
Bg1	7-42	29.00	27.00	43.00	Clay	51.85
Bg2	42-61	33.00	23.00	44.00	Clay	52.23
Bg3	61-100	40.00	21.00	39.00	Clay loam	55.26
Farm 2 (Soil Profile 2 - Brgy. Cabugao)						
Ap	0-19	30.00	11.00	59.00	Clay	67.12
AB	19-33	25.00	15.00	59.00	Clay	57.61
Btg1	33-53	19.00	11.00	69.00	Clay	61.70
Btg2	53-70	23.00	9.00	68.00	Clay	76.42
Btg3	70-100	23.00	7.00	70.00	Clay	60.27
Farm 3 (Soil Profile 3 - Brgy. Ambilay)						
Ap	0-16	22.00	31.00	47.00	Clay	63.38
AB	16-25	25.00	27.00	47.00	Clay	46.10
Btg1	25-42	23.00	27.00	50.00	Clay	58.62
Btg2	42-71	23.00	19.00	58.00	Clay	43.97
Btg3	71-100	19.00	19.00	62.00	Clay	43.79
Farm 4 (Soil Profile 4 - Brgy.Pasugue)						
Ap	0-13	27.00	25.00	48.00	Clay	79.03
AB	13-25	34.00	21.00	45.00	Clay	65.00
Bwg	25-39	39.00	19.00	42.00	Clay	55.56
Btg1	39-59	28.00	7.00	65.00	Clay	64.18
Btg2	59-100	31.00	9.00	59.00	Clay	69.23
Farm 5 (Soil Profile 5 - Brgy. Cadio)						
Ap	0-14	32.00	23.00	45.00	Clay	53.16
Btg1	14-37	24.00	9.00	67.00	Clay	47.59
Btg2	37-64	21.00	9.00	69.00	Clay	54.14
BC	64-78	53.00	17.00	29.00	Sandy clay loam	65.44
C	78-100	50.00	19.00	31.00	Sandy clay loam	58.67
Farm 6 (Soil Profile 6 - Brgy. Calaan)						
Ap	0-14	40.00	17.00	43.00	Clay	46.39
Btg	14-31	29.00	11.00	59.00	Clay	46.02
Bwg	31-54	29.00	25.00	46.00	Clay	43.75
BC	54-70	31.00	7.00	61.00	Clay	37.96
C	70-100	56.00	7.00	37.00	Sandy clay	50.31

Soil Chemical Properties

Soil pH refers to the negative logarithm of hydrogen ion concentration or the measure of alkalinity or acidity of a particular soil (Mccauley 2009). In Figure 4a, the soil depth function indicated that Farm 5 is the only profile with a pH value of 5.74 in the Ap horizon to 4.83 in the C horizon, which is becoming increasingly acidic. Subsoil acidity often occurs due to excessive cation being absorbed by the plants, and acid is produced as a reaction in the root zone (Tang 2012). On the other hand, Farms 1, 2, 3, 4, and 6 have a pH value that ranges from 5.15 to 6.43 in the Ap horizon, and 5.16 to 7.47 in the lower Btg3, BC, and C horizon. The rise in pH value often occurs in the C horizon due to the presence of free lime, natural gypsum, and soluble salts (Sale et al 2021).

Soil organic matter (SOM) is the term given to any material that is originally a part of a living organism, either plant or animal, that is turned back into the soil through decomposition (Bot & Benites 2005). In the soil profile (Figure 4b), organic matter content decreases at a lower soil horizon with amounts ranging from 1.77% to 2.81% at the Ap horizon, and 1.14 to 0.37 at the lower Bg3 and C horizon of Farms 1 and 6, respectively. These amounts are relatively low since most productive agricultural soils have a SOM content ranging from 3% to 6% (Fenton et al 2008). This can be due to the organic matter concentration that is greater in the uppermost soil horizon as an effect of residue turnover from plant and animal debris (Gasch & DeJong-Hughes 2019).

Total Nitrogen (%) is another determinant of soil quality, fertility, and productivity. The decrease in the amount of N in agroecosystems proportionally reduced the nutrient supply of the soil, its fertility, and productivity (Al-Kaisi et al 2005; Gray & Morant 2003; Li et al 2022). As shown in the depth function of Figure 4c. Higher content of total N can only be found at the uppermost Ap horizons, while it decreases at greater soil depths. The highest value of Total N in the Ap horizon ranges from 0.167% to 0.216%. However, at lower soil depths, the least value ranges from 0.04% in the Btg3 horizon of Farm 3 to 0.101% in the Bg3 horizon of Farm 1. The reduction in total nitrogen content of the soil may be correlated with the fact that the poorly drained conditions of paddy soils resulted in increased denitrification as the microorganisms use the oxygen in nitrate ions for them to function and decompose efficiently (Soana et al 2021). Denitrification progresses immediately after 2 to 3 days of saturation of the soil with water (Lamb et al 2019).

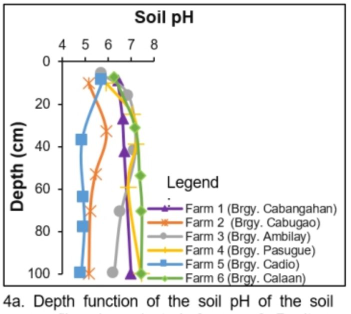
In agricultural soils, Phosphorus (P) availability is the most limiting factor for efficient crop growth and development (Ziadi et al 2013) since it is only available in pH-neutral soils. Soil P exists in two forms. These are the inorganic and organic P that makes up the total soil P (Prasad & Chakraborty 2019). In the depth functions of the profile of the selected farms studied (Figure 4d) it was found that the soil with a neutral to near alkaline soil pH, P has an increased amount, such as in Farms 1 (8.98 – 13.44 mg kg^{-1}) and 6 (3.08 - 17.31 mg kg^{-1}) . However, the least values were found in Farms 2 (0.15 – 0.86 mg kg^{-1}) and 5 (0.10 – 0.50 mg kg^{-1}), which are highly acidic soil profiles. This happens because P tends to be fixed with aluminum and iron in highly acidic soil, making it unavailable for plant use. Also, if the pH exceeds 7.5, P unavailability occurs due to being fixed with calcium as it exhibits too much alkaline condition (Chakravorty 2018).

Potassium (K) is a plant macronutrient that is essential for plant growth. It influences the transport of water, nutrients, and carbohydrates. K is also needed to regulate stomatal opening and closing and for enzyme activation during starch and ATP production. In soils, the availability of K is influenced by the parent material and the effect of weathering processes in this material. Although the amount of K is relatively greater in soils than other nutrient elements, a smaller quantity is only made available for plant use since most of it is a structural component of soil minerals and is not readily supplied (UMN 2018).

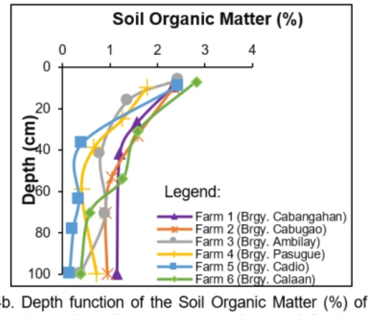
The Results in Figure 4e revealed that the highest amount of K is noted in Farm 6, where it has a mean of 0.66 cmol kg^{-1} in the Bwg horizon and 0.44 cmol kg^{-1} in the C horizon. On the other hand, the least values were still noted in Farm 3, which is 0.08 cmol kg^{-1} in the AB horizon, and 0.06 cmol kg^{-1} in the Btg3 horizon. This indicates that the availability of exchangeable K is also limited at lower soil depths. The limitation in exchangeable K occurs as a consequence of alternate wetting and drying in the subsoil since this will dehydrate the $K+$ ions at the interlayer spaces of the 2:1 clay mineral (illite, vermiculite, and smectite), thus resulting it to be fixed or becoming part of the mineral structure making it unavailable or inaccessible for crop use (Barak 1999).

In Figure 4f, the soil depth function shows that among the soil profiles, the highest amount of exchangeable Al can be found in Farm 5 (particularly in the Btg2 horizon, with a mean value of 12.68 cmol kg^{-1}), where the least pH value was also noted. In contrast, the least amount of exchangeable Al (0.027 cmol kg^{-1}) had been noted in soil profiles with neutral to slightly alkaline soil p pH, such as in Farms 1, 3, 4, and 6. This only proves that at lower pH, the dominant effect of Al is noted, and acidity and low fertility can be expected

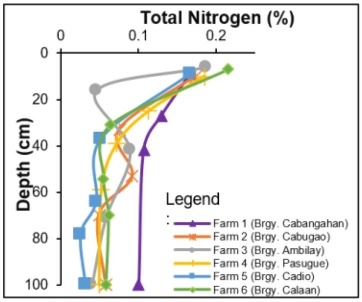
Cation exchange capacity (CEC) is defined as the ability of soil to sorb positively charged ions. It is vital to soil properties affecting the stability of soil structure, availability of most soil nutrients, and soil pH (Hazleton & Murphy 2007). According to Nakao et al (2021), the CEC of Philippine soils has increased over the past 50 years (from 1960 to 2010) due to the higher smectite content in silt fraction and sediment transportation through irrigation. The findings in Figure 4g contradict the observation of Nakao et al (2021). Wherein, the depth function of the soil profile revealed that the CEC values of long-term cultivated paddy soils are relatively low, ranging from 2.22 cmol kg^{-1} to 5.08 cmol kg^{-1}. It can be noticed that CEC increases in the subsoil in contrast to surface soil in Farms 2, 5, and 6, while decreasing values were obtained in Farms 1, 3, and 4. The increase of CEC values in the B horizon of most soils can be correlated with an increase in clay content. At the soil surface, the humus is responsible for greater CEC (Sanon et al 2022).



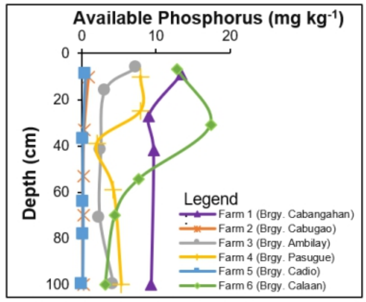
4a. Depth function of the soil pH of the soil profiles in selected farms of Panitan, Capiz, Philippines



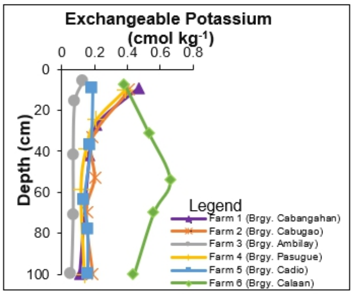
4b. Depth function of the Soil Organic Matter (%) of the soil profiles in selected farms of Panitan, Capiz, Philippines



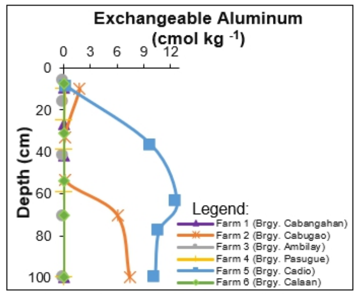
4c. Depth function of the Total Nitrogen (%) of the soil profiles in selected farms of Panitan, Capiz, Philippines



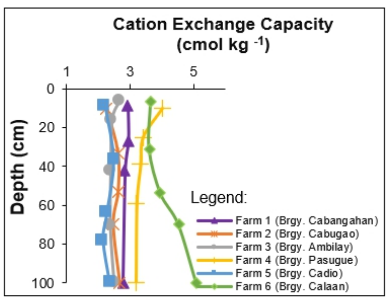
4d. Depth function of the Available Phosphorus (mg kg^{-1}) of the soil profiles in selected farms of Panitan, Capiz, Philippines



4e. Depth function of the Exchangeable Potassium (cmol kg^{-1}) of the soil profiles in selected farms of Panitan, Capiz, Philippines



4f. Depth function of the Exchangeable Aluminum (cmol kg^{-1}) of the soil profiles in selected farms of Panitan, Capiz, Philippines



4g. Depth function of the Cation Exchange Capacity (cmol kg^{-1}) of the soil profiles in selected farms of Panitan, Capiz, Philippines

Figure 4. Soil Chemical Properties

Soil Biological Property

Microbial Activity (Soil Respiration)

Soil respiration is a process by which Carbon Dioxide (CO_2) is produced through the activity of soil microorganisms. This is the source of significant CO_2 fluxes in a global carbon cycle (Phillipes & Nickerson 2013). In Figure 5, the CO_2 evolution of the surface soil at 0-20 cm soil depth is shown. It has been found that after the first day the mean values of CO_2 respired range from 29.48 CO2 100 g^{-1} in Farm 6 to 46.43 CO_2 100 g^{-1} in Farm 1. However, fluctuation occurs on the third and fifth days of incubation. The values obtained only range from 15.85 CO_2 100 g^{-1} in Farm 2 to 38.69 CO_2 100 g^{-1} in Farm 1 on the third day of incubation. In comparison, 23.95 CO_2 100 g^{-1} to 29.11 CO_2 100 g^{-1} of CO_2 is respired after the fifth day of incubation. This indicates that respiration is highly variable within a given period of time. Wherein, the occurrence of a high soil respiration rate in the short term is not necessarily needed as it reflects a very unstable soil system and might lead to the loss of organic matter when the areas are subjected to intensive cultivation and other factors (USDA 2014).

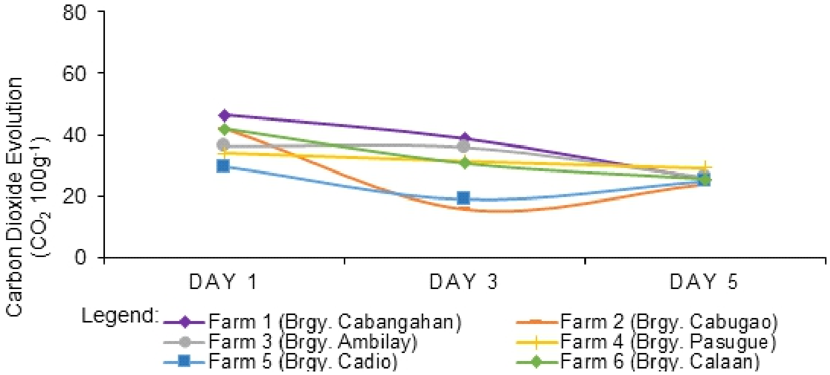


Figure 5. Soil respiration (CO_2 100g^{-1} of soil) of paddy soils in selected farms of Panitan, Capiz, Philippines at 0-20cm soil depth

Fertility Status of Paddy Soils

The soil fertility and suitability of paddy soils in selected farms of Panitan, Capiz, Philippines, at 0-20 cm soil depth are shown in Table 3. The different values obtained for each parameter were evaluated using the criteria set by Landon in 1991. Wherein, at 0-20cm, the following properties and the amount and availability of nutrients were noted. For the texture, clay, a fine-textured soil, is dominant among the farms studied. In addition, clay-to-clay loam soil texture is best suited for paddy rice cultivation (Dou et al 2016), increasing its favorability for rice cultivation. In terms of porosity, ≥ 50% is ideal for paddy cultivation. Since lower bulk density values were obtained, an increase in favorability when it comes to soil porosity was also noted in all farms. For consistency, slightly plastic (spl) and slightly sticky (sst) when wet, and friable (fr) when moist were obtained. For Farms 1, 3, 4, 5, and 6, the soil pH ranges from 5.98 to 6.91, which is moderately acidic to neutral. On the other hand, Farm 2 has a pH value of 5.43 which is strongly acidic, making it a constraint for paddy cultivation. However, the SOM (%) and Total N (%) content of all farms exhibits a constraint since its availability only ranges from 1.79% to 2.37% for SOM, and 0.14% to 0.17% for Total N. For Available P, 0.26 mg kg^{-1} to 0.50 mg kg^{-1} for the least values were observed in the case of Farms 2, 3, 4, and 5. For Farms 1 and 6, 13.12 mg kg^{-1} and 12.52 mg kg^{-1} of available P were found. For exchangeable K, the six farms exhibit a conducive amount which ranges from 0.21

cmol kg^{-1} to 0.46 cmol kg^{-1}.

For the six soil profiles, the following fertility status was found. Very strongly acidic to slightly alkaline for soil pH, which is 4.83 to 7.47; very low to a low amount of SOM, which is 0.15% to 2.81%; very low to medium amount of total N which is 0.026% to 0.216%, low to moderate available P which is 0.1 mg kg^{-1} to 17.31 mg kg^{-1}, low to moderate exchangeable K (0.06 cmol kg^{-1} to 0.7 cmol kg^{-1}) and very low to low CEC which is 0.027 cmol kg^{-1} to 12.68 cmol kg^{-1}.

Table 3. Soil fertility and suitability of paddy soils in selected farms of Panitan, Capiz, Philippines at 0 – 20 cm soil depth

SOIL PROPERTIES	THRESHOLD SURFACE SOIL (AT 0 -20CM SOIL DEPTH) VALUE [A]	SURFACE SOIL SAMPLE [B]					
		1	2	3	4	5	6
Soil Texture	fine	+	+	+	+	+	+
Porosity (*%f*)	> 50%	+	+	+	+	+	+
Bulk density (g/cm^{-3})	< 1.45	+	+	+	+	+	+
Consistency	fr; sst; spl	+	+	+	+	+	+
pH_{H2O}	5.5 – 7.0	+	-	+	+	+	+
SOM (%)	> 3.0	-	-	-	-	-	-
Total N (%)	> 0.2	-	-	-	-	-	-
Available P (mg kg^{-1})	> 8 - 15	+	-	-	-	-	+
Exchangeable K (cmol kg^{-1})	> 0.20	+	+	+	+	+	+

[A]Threshold value of each parameter were adapted from Asio (1996)
[B]Plus (+) sign indicates that the soil property is favourable for paddy cultivation; minus (-) sign indicates that the soil property is a constraint to paddy cultivation; fr, friable; sst, slightly sticky, spl, slightly plastic

CONCLUSIONS

Based on the findings of the study, the following conclusions were drawn;

1. The surface and profile samples have a Clay texture. In terms of horizon development, the following were the sequences, AP-Bg (Farm 1), Ap-AB-Btg (Farms 2, and 3), Ap-AB-Bwg-Btg (Farm 4), Ap-Btg-BC-C (Farm 5), and Ap-Btg-Bwg-BC-C for Farm 6. Due to clay-textured horizon and shallow water table, all of the selected farms have impeded drainage with fine to coarse and faint to prominent mottles, weak to moderately fine and medium sub-angular blocky, friable in consistency when moist, and slightly sticky and slightly plastic to sticky and plastic when wet. Level topography and alluvium parent material exhibit a dominant influence on soil profile development. The highest soil microbial activity was noted at first day after incubation with Farm 5, who have obtained the least, and Farm 1 with the highest activity.
2. The soils in all farms (Farms 1-6) are less fertile, having a strongly acidic to slightly alkaline soil pH, very low to low SOM, very low to medium total N, low to moderate available P, and very low to low CEC.
3. Integration of rice straw after harvest and practice of green manuring of legumes can be done in order to increase the SOM and Total N content of the paddy soils of selected farms. The combined application of organic and inorganic fertilizers can also be done.

RECOMMENDATIONS

Based on the findings of the study, all of the six profiles have a low fertility status due to the number of years that it has been devoted to paddy rice cultivation. Thus, it is recommended to integrate the rice straws after harvest to increase the SOM content. Green manuring with leguminous crops can also be done prior to land preparation to increase SOM and soil fertility. Instead of conventional tillage (plowing and harrowing twice), reduced tillage can be done (plowing first and then harrowing after a week). Periodic soil testing should also be done to apply an adequate amount of fertilizer based on the recommendation that it will generate. Lastly, in attaining the recommended rate, organic and inorganic fertilizers can be applied. The inorganic fertilizers will be an immediate source of nutrients for the growing rice, while organic fertilizers will enhance the physical and chemical, as well as biological properties of the soil in the long run to enhance and maintain the productivity of the area.

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