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Nutrient Availability and Biological Properties of Paddy Soils Under Rainfed Traditional "Payatak" Farming Systems in Catubig Valley, Philippines

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ABSTRACT

To understand the long-term effects of payatak and conventional rice farming system on soil properties and soil quality, a soil survey was conducted in existing "payatak" and conventional rice fields in Catubig Valley, Northern Samar, Philippines. Chemical analyses revealed that soils under "payatak" are more acidic, with low *EC,* OM, and N content compared to those soils from conventional rice farms. However, available P and exchangeable K in "payatak" soils were higher than those in conventional. The available N varied significantly with time and sampling area and the mineral N levels fluctuated greatly within three weeks after land preparation. The BiologEcoPlate™ and subsequent correlation analysis have shown a partial characterization of microbial functional community attributed to several factors leading to differences in chemical properties of the two rice farming systems. These results imply that the levels of OM and the amount of exchangeable K could trigger a distinct microbial community functional structure. Variations in soil pH, *EC,* and the amounts of nutrients have also caused a shift of the microbial functional diversity as represented by correlations between Shannon–Weaver indices. Overall, the results would indicate that long term "payatak" and conventional rice farming system would result in different soil nutrient status and distinct microbial functional community which may affect the overall productivity and soil quality. Further analysis should be done to establish the relationship between soil microbial properties data onto long term productivity in paddy soils.

Keywords: Available P, Exchangeable bases, Microbial functional structure, N-mineralization, Soil enzyme activities.

INTRODUCTION

Conversion of traditional farming systems to intensive agricultural production systems is normally promoted to increase productivity and meet the demands of food security. The same scenario is occurring in traditional rice farming areas in Catubig Valley, Philippines where shifting to a much better production system is promoted among farmers to increase productivity. Currently, the annual rice production in Catubig Valley is only 1.25 tons ha^{-1} (BAS-Catarman, 2012) and this low productivity is attributed to inadequate land area serviced with irrigation facilities (mainly rainfed) and very low adoption of agricultural technologies for rice such as using certified seeds and agricultural inputs (Rebadulla, 1999). About 80% remained under rainfed system (BAS-Catarman, 2012) and cultivated under the traditional-rainfed "payatak" farming system which existed for the past centuries. Recently, development projects are

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implemented aimed at improving the irrigation facilities, farm-to-market roads, and human-capital enhancement programs (Toru, 2007). This project aimed to boost the economic activity and productivity of agriculture-based communities in the locality.

Correspondingly, changes in the farming system towards intensive conventional farming are expected. However, studies have shown that conventional agriculture is non-sustainable and associated with serious environmental problems (Ayoubi *et al*., 2011). To avoid these unfavorable impacts of conventional rice farming, farming systems should be designed based on the capability and suitability of the resources though understanding the soil resource properties and processes. Understanding these properties and processes especially during the transition period is a requisite for identifying appropriate components of sustainable farming systems (Emami *et al.,* 2012).

Specifically, the paddy soils of Catubig Valley should be assessed in order to properly identify alternative/s and efficient agricultural practices relevant in improving and creating a sustainable-environment friendly production system. Assessment of soil chemical and biological properties affecting nutrient availability in the study area under conventional and traditional rice farming systems is necessary in the formulation of site-specific fertilizer recommendations, the development of nutrient management technologies, and identification efficient agricultural practices to increase rice productivity (Emami *et al.,* 2012). Aside from these, there was no existing published report on the nutrient dynamics in soils under traditional payatak system that could be useful as a tangible scientific basis of encouraging farmers to reconsider their traditional practices of land preparation and adopt the best practices of land preparation method for optimum rice yield. Therefore, this paper assessed the soil chemical and biological properties of major rainfed lowland areas devoted to traditional and conventional rice farming in Catubig Valley. We also compared the soil chemical properties and temporal variation of N dynamics during land preparation to crop establishment in order to identify a strategy for efficient cropping pattern/s, soil nutrient balance and management.

MATERIALS AND METHODS

Site and Treatment Description

The study area was situated in the flood plains of the Catubig river-watershed (12.4088° N, 125.0529° E) devoted to rice farming under the municipalities of Catubig, Laoang and Las Navas, Northern Samar, Philippines. The soil of the area belongs to Catubig Series, which has developed from alluvial deposits, level to slightly undulating and shallow water table (1-1.5 m). The majority of the land area is utilized for rainfed rice production and dominated with grasses during the fallow period after rice cultivation. Study area falls under the intermediate type climate, which has no distinct dry and wet seasons. The rainiest months are October to January while the driest is the month of May. The average annual rainfall is 3,409 mm.

The study compared the attributes of soil from payatak and conventional lowland rice farming practices. These 2 farming systems constituted the 2 treatments and the different sampling area represents the replicates. In delineating and classifying the sampling area, the characteristics of the farming system were the bases. Treatment 1 includes those under rainfed payatak rice farming systems while treatment 2 was those areas under the conventional lowland rice farming. The characteristics of each farming system based on actual observation and interview with farmers were presented in Table 1. There were a total of 10 sampling areas for each farming system strategically located in the lowland and flood plains of Catubig Valley (at least for treatment 1 because majority of the land in the study area still practices the "payatak" rainfed system). The sampling site and attributes were presented in Table 2.

Table 1. Farming system description between "payatak" and conventional rice farming.

Farming components	Payatak rice farming	Conventional rice farming
1. Irrigation	Rainfed	Irrigated
2. Land preparation	Puddling and harrowing usually done in one session using carabao and wooden harrow ("pakaras") at the onset of continued rain	Two-stage plowing and harrowing, ample time for organic matter decomposition prior to transplanting
3. Weeding Operations	Not performed	Usually by mechanical weeding or hand pulling
4. Fertilization	No chemical or organic fertilization. Weeds are incorporated during land preparation. Potential source of nutrient include crop residue, incorporated weeds and carabao manure and urine when the area are used as temporary pasture during fallow period	Fertilized at the recommended rate at 90-150 kg N ha^{-1}, 60-90 kg P_2O_5 ha^{-1} and 60-90 kg K_2O ha^{-1}. 50% of the NPK rate are applied basally while the remaining 50% at panicle initiation
5. Number of cropping per year	Once a year with 7 months fallow period	Usually 2 crops a year with shorter fallow period
6. Pest and disease control, prevention	Minimal: Do not use chemical pesticide	Optimum

Soil Sample Collection, Preparation and Analysis

In this study, there were two-sets of soil sampling conducted in the study area. The first set of samples were obtained in all identified sampling sites and analyzed for selected chemical and biological properties. The second set of samples was obtained from 10 selected sites (5 from each group) for the purpose of evaluating N availability within 30 days from land preparation.

Soil Sampling for Chemical and Biological Characterization

In selected sampling sites, soil samples representing the area and method of rice cultivation were collected in August-September, 2013 which is at the onset of rice cultivation in the study area. Three composite samples were gathered to represent each sampling site (farm). The topsoil (about 20 cm) was collected in at least 4 sampling points to represent a composite sample (i.e. 12 sampling points in each farm). The composite sample was properly labeled and partitioned into 2 portions for chemical and biological analysis. Samples for chemical analysis were immediately frozen while those samples for biological analyses were stored at 4°C until it was analyzed at the Crop Production Laboratory, College of Agriculture and Life Sciences, Kyungpook National University, Daegu, South Korea. Frozen soil samples were freeze-dried prior to chemical analysis. Standard procedures established by the laboratory were strictly followed for chemical analysis of soil samples.

Soil Sampling for N Availability Dynamics

To compare the available nitrogen dynamics in soil between "payatak" and

Table 2. Sampling site description.

Sampling code	Location	Coordinates	Treatment Assignment/ Site Description
CGGN-1	Brgy. Cagugubngan, Catubig	12° 22' 49.4" N, 125° 03' 54.7" E	Payatak–flat to nearly level, once a year cropping
OSMN-1	Brgy. Osmena, Catubig	12° 22' 37.7" N, 125° 04' 12.1" E	Payatak–flat to nearly level, once a year cropping
CLNN-1	Brgy. Calingnan, Catubig	12° 24' 23.2" N, 125° 03' 36.2" E	Payatak–flat to slightly undulating, once a year cropping
MGTD	Brgy. Magtuad, Catubig	12° 22' 03.1" N, 125° 04' 41.4" E	Payatak–flat to slightly undulating, once a year cropping
HBBL-1	Brgy. San Jose, Catubig	12° 22' 54.4" N, 125° 06' 26.8" E	Payatak–flat to nearly level, once a year cropping
ANGO-1	Brgy. Anongo, Catubig	12° 23' 00.4" N, 125° 07' 24.7" E	Payatak–flat to slightly undulating, once a year cropping
IRWH-1	Brgy. Irawahan, Catubig	12° 25' 28.3" N, 125° 02' 16.4" E	Payatak–flat to nearly level, once a year cropping
OLRS	Brgy. Oleras, Laoang	12° 26' 49.6" N, 125° 02' 16.7" E	Payatak–flat to nearly level, once a year cropping
BUKD	Brgy. Bukid, Las Navas	12° 21' 49.9" N, 125° 01' 55.4" E	Payatak–flat to nearly level, once a year cropping
ROBS	Brgy. F. Robis, Las Navas	12° 21' 20.1" N, 125° 02' 19.8" E	Payatak–slightly undulating, once a year cropping
CGGN-2	Brgy. Cagugubngan, Catubig	12° 22' 58.8" N, 125° 03' 50.5" E	Conventional-seed-tech farm, flat to nearly level, twice a year cropping
OSMN-2	Brgy. Osmena, Catubig	12° 22' 37.7" N, 125°04'12.1"E	Conventional-flat to nearly level, twice a year cropping
HBBL-3	Brgy. San Jose, Catubig	12° 22' 55.7" N, 125° 06' 22.6" E	Conventional-seed-tech farm, flat to nearly level, twice a year cropping
MGTD-2	Brgy. Magtuad, Catubig	12° 22' 31.9" N, 125° 06' 21.0" E	Conventional-seed-tech farm, flat to nearly level, twice a year cropping
IRWH-2	Brgy. Irawahan, Catubig	12° 25' 28.4" N, 125° 02' 07.6" E	Conventional-RIARC demo farm, flat to nearly level, thrice a year cropping
IRWH-3	Brgy. Irawahan, Catubig	12° 25' 35.2" N, 125° 02' 22.0" E	Conventional RIARC demo farm, flat to nearly level, thrice a year cropping
IRWH-4	Brgy. Irawahan, Catubig	12° 25' 24.3" N, 125° 02' 10.0" E	Conventional RIARC demo farm, flat to nearly level, thrice a year cropping
OLRS-2	Brgy. Oleras, Laoang	12° 27' 11.1" N, 125° 02' 03.8" E	Conventional PGMA-demo farm, flat to nearly level, thrice a year cropping
OLRS-3	Brgy. Oleras, Laoang	12° 27' 38.5" N, 125° 01' 56.8" E	Conventional-PGMA demo farm, flat to nearly level, thrice a year cropping
BUKD-2	Brgy. Bukid, Las Navas	12° 21' 40.2" N, 125° 02' 14.9" E	Conventional, flat to nearly level, twice a year cropping

conventional system within 30 days from the start of land preparation, five (5) sampling sites from each farming system were selected and established from the sites already mentioned. The sampling sites for the "payatak" system are in CGGN 1, OSMN 1, CLNN 1, IRWH 1 and BUKD-1; while for conventional systems it is HBBL2, IRWH 2, IRWH 3, OLRS 2 and BUKD 2; whose site descriptions were previously presented in Table 2. For each sampling site, five (5) core samples from the upper 10 cm in the surface horizons were collected and formed into a composite sample. The composite sample was immediately frozen prior to laboratory analysis. Samples were collected in each site at 2 days interval.

Soil Chemical Characterization

The samples were analyzed for organic matter (Walkey-Black Method), total nitrogen (N) – Kjeldahl digestion followed by steam distillation using boric acid receiver, followed by standard acid titration, available P by Bray II method– 0.1N HCl-0.03N ammonium fluoride extraction followed by Atomic Absorption Spectrophotometer (AAS, Shimadzu AA 660); exchangeable K, Ca, Mg, Mn, Na– by 1N ammonium acetate (pH 7.0) extraction followed by AAS; soil pH and *EC* were measured on a 1:5 (soil:water) suspension using an electrode-multi parameter analyzer (CONSORT C535) and the carbon and nitrogen contents were determined using CHNS-elemental analyzer (FlashEA 1112 Series, Thermo Electron Corp., Rodano, Italy). Each composite sample was analyzed three times to obtain the average values and check the accuracy of the analyses while for C and N analysis, each composite samples were analyzed in five replicates.

Soil Enzymatic Activities

The soil samples were assayed for enzyme activities using standard procedures within 1 week after sampling. The soil moisture content was adjusted to field capacity prior to biological assay using sterile distilled water. The activities of alkaline phosphatase (EC 3.1.3.1) and acid phosphatase (EC 3.1.3.2) were determined as described by Tabatabai (1994). Arylsulfatase (EC 3.1.6.1) and α-D-glucosidase (EC 3.2.1.21) were determined as previously described by Lu *et al.* (2003) and Wang *et al.* (2006). Urease (EC 3.5.1.5) activity was determined with the method of Kandeler (1995). FDA hydrolysis activity was analyzed based on the methods of Schniirer and Rosswall (1982) and Adam and Duncan (2000).

Soil Microbial Community Level Physiologic Profile and Microbial Activity

The soil microbial activity was evaluated based on substrate (sole-carbon source) utilization profiles that were established using Biolog EcoPlate™ (Biolog, Hayward, CA, USA). The preparation and inoculation of the soil samples took place within 10 days of sampling. The procedure employed in the use of Biolog EcoPlate™ and the calculations of average well color development, was based on the procedure outlined in Yamamoto *et al.* (2008). The Shanon-Weaver index (*H*, richness and evenness of response) and Richness (R, the number of positive wells on the BiologEcoPlate™) of bacterial communities were calculated based on the BiologEcoPlate™ readings after 72 hours of incubation (Yamamoto *et al.*, 2008).

Comparison of Available Nitrogen Between "Payatak" and Conventional System

The available N in frozen samples was determined (after 1 day thawing) by extracting the mineral N (mostly NH_4^+ and NO_3^-) with 1M potassium chloride at pH 7.0 based on Yamamoto *et al.* (2008). Extraction was performed by shaking the

mixture of 10g of soil with 50 ml extracting solution for 1hr followed by filtration (Whatman# 42). The extract was subjected to closed-system distillation using 3N NaOH and boric acid receiver, followed by standard acid titration. Frozen soil samples were freeze-dried prior to available N analysis. The samples were analyzed in duplicates.

The dynamics of available nitrogen within 30 days from the onset of land preparation was evaluated by calculating the net mineralization or net immobilization of available N at different sampling periods. The change in concentration from the initial level to every sampling period was calculated as net mineralization (positive) or net immobilization (negative).

Statistical Analysis

The data on soil chemical properties, the average well color development, richness and the Shanon-Weaver index were statistically analyzed using the SAS system for windows, version 8.01 (SAS Institute, USA). The mean values per treatment were compared using t-test. The Optical Density (OD) data from the BiologEcoPlate™ were subjected to factor analysis by principal component analysis using SPSS (PASW Statistics 17.0.3). The *OD* of individual substrate with high correlation to the extracted PCs was subjected to *T*-test. In addition, correlation analysis was performed between the soil biological data and some soil chemical properties.

RESULTS

Chemical Properties of Paddy Soils in the Catubig Valley

Soil pH and Electrical Conductivity: The soil pH of rice fields under traditional payatak farming systems were slightly acidic (pH 4.99) compared to those samples collected from conventional rice farming systems which is about 5.82 (Table 3). Soil samples collected from rice fields under payatak farming systems have slightly lower *EC* (Range: 0.24~0.44 dS m^{-1}, Mean: 0.344 dS m^{-1}) compared to those samples collected from conventional rice farming systems (Range: 0.32~0.48 dS m^{-1}, Mean: 0.391 dS m^{-1}) when compared within sampling area (Table 3).

Soil Organic Matter (SOM) and Nitrogen: The SOM and N content from rice fields under payatak farming systems are significantly lower compared to those samples collected from conventional rice farming systems when compared within sampling area (Table 3). On the average, the SOM in conventional paddy soil is 22.9% higher than the OM from payatak paddy soils. The average total N content in payatak paddy soils was 29.9% lower compared to those from conventional paddy soils (Table 3).

Available Phosphorus: The available P from payatak paddy soils was significantly higher compared to those from conventional paddy soils when compared within sampling area (Table 3). The available P of soils from conventional rice farming system ranged from 32~44 mg kg^{-1} soil with a mean of 38.75 while those from payatak ranged from 39~48 mg kg^{-1} soil with a mean of 44.12.

Exchangeable Bases: Soils collected from payatak paddy soils have higher exchangeable K compared to those collected from conventional paddy soils (Table 4). The exchangeable Ca and Mg have no consistent discernible differences between sampling areas and between the cropping systems, the exchangeable Na was higher in conventional rice farms compared to the payatak system (Table 4).

Nitrogen Dynamics: The available N in the payatak and conventional system ranged from 62 to 198 mg kg^{-1} and from 62 to 186 mg kg^{-1}, respectively (Figure 1a). In both rice farming systems, the available N declined continuously until 12 to 18 days after land preparation, and started to increase onwards. Net N immobilization in payatak system occurred 2 days after the start of land

Table 3. Soil pH, Electrical Conductivity (EC, dS m^{-1}), organic matter (OM, g kg^{-1}), total N (%) and available P (mg/kg) of soils collected from payatak and conventional paddy soils in Catubig Valley.[a]

Sampling Site	pH		*EC*		OM		Total N		Avail. P	
	CON	PYT	CON	PYT	CON	PYT	CON	PYT	CON	PYT
CGGN	4.88±0.01	4.58±0.02	0.42±0.01	0.38±0.03	27±0.2	23±0.4	0.34±0.02	0.28±0.01	40±0.2	44±0.1
OSMN	5.00±0.01	4.86±0.06	0.41±0.04	0.36±0.04	22±0.4	16±0.2	0.22±0.04	0.22±0.01	39±0.1	42±0.2
CLNN	5.38±0.12	5.12±0.12	0.38±0.02	0.33±0.02	23±1.2	17±0.3	0.28±0.02	0.24±0.0.2	32±0.3	39±0.1
MGTD	5.40±0.08	4.98±0.08	0.32±0.03	0.24±0.06	25±0.8	21±0.2	0.34±0.02	0.27±0.01	42±0.2	44±0.2
HBBL	5.82±0.10	5.23±0.10	0.38±0.04	0.32±0.04	24±0.2	18±0.1	0.22±0.01	0.22±0.04	36±0.4	44±0.2
ANGO	5.64±0.06	5.32±0.12	0.38±0.06	0.34±0.02	28±0.3	24±0.2	0.36±0.03	0.32±0.03	39±0.2	46±0.3
IRWH	5.42±0.04	4.92±0.04	0.48±0.02	0.44±0.02	32±1.2	18±0.2	0.42±0.02	0.32±0.06	44±0.1	48±0.1
OLRS	5.48±0.08	4.92±0.02	0.36±0.02	0.34±0.04	23±0.8	19±0.1	0.26±0.04	0.24±0.02	38±0.1	46±0.2
Mean	5.38	4.99*	0.391*	0.344	25.5	20.75*	0.30	0.26*	38.75	44.12*
Range										
Max	5.82	5.23	0.48	0.44	32	28	0.42	0.32	44	48
Min	4.88	4.58	0.32	0.24	22	16	0.22	0.22	32	39

[a] Data are the average and the standard deviation in each sampling site. CON is Conventional and PYT is Payatak. * In the payatak column would indicate significant difference against the conventional column within the same site by *t*-test at 5% level.

Table 4. The concentration of exchangeable bases of soils collected from payatak and conventional paddy soils in Catubig Valley.[a]

Sampling Site	K		Ca		Mg		Na		Total	
	cmol(+) kg^{-1}									
	CON	PYT	CON	PYT	CON	PYT	CON	PYT	CON	PYT
CGGN	0.31±0.02	0.45±0.02	12.15±0.10	13.52±0.10	8.50±0.10	8.21±0.06	0.12±0.02	0.10±0.03	21.08±0.80	22.28±0.30
OSMN	0.18±0.02	0.32±0.02	21.17±0.20	19.14±0.30	5.42±0.08	6.21±0.08	0.42±0.04	0.21±0.04	27.19±0.70	25.88±0.60
CLNN	0.29±0.02	0.40±0.02	21.75±0.20	23.24±0.20	4.28±0.06	3.42±0.10	0.38±0.03	0.24±0.02	26.70±0.30	27.30±0.70
MGTD	0.28±0.02	0.38±0.02	10.9±0.30	10.3±0.20	6.42±0.10	5.48±0.08	0.26±0.01	0.18±0.03	17.86±0.60	16.34±0.80
HBBL	0.31±0.02	0.43±0.02	16.95±0.20	15.42±0.20	6.28±0.04	6.84±0.10	0.24±0.02	0.12±0.02	23.78±0.40	22.81±0.60
ANGO	0.39±0.02	0.48±0.02	13.95±0.10	16.35±0.30	6.24±0.06	5.89±0.06	0.48±0.08	0.28±0.04	21.06±0.30	23.00±0.70
IRWH	0.33±0.02	0.38±0.02	21.20±0.20	18.62±0.10	8.24±0.08	8.65±0.05	0.35±0.04	0.24±0.06	30.12±0.20	27.89±0.30
OLRS	0.24±0.02	0.34±0.02	24.25±0.10	16.24±0.20	8.68±0.10	9.20±0.10	0.27±0.02	0.14±0.02	33.44±0.20	25.92±0.40
Mean	0.29	0.40*	17.79	16.60ns	6.76	6.74ns	0.32	0.19*	25.15	23.93
Range										
Max	0.39	0.48	24.25	23.24	8.68	9.2	0.48	0.28	33.44	27.89
Min	0.18	0.32	10.9	10.3	4.28	3.42	0.12	0.1	17.86	16.34

[a] Data are the average and the standard deviation in each sampling site. CON is Conventional and PYT is payatak.* In the payatak column would indicate significant difference against the conventional column within the same site by *t*-test at 5% level.

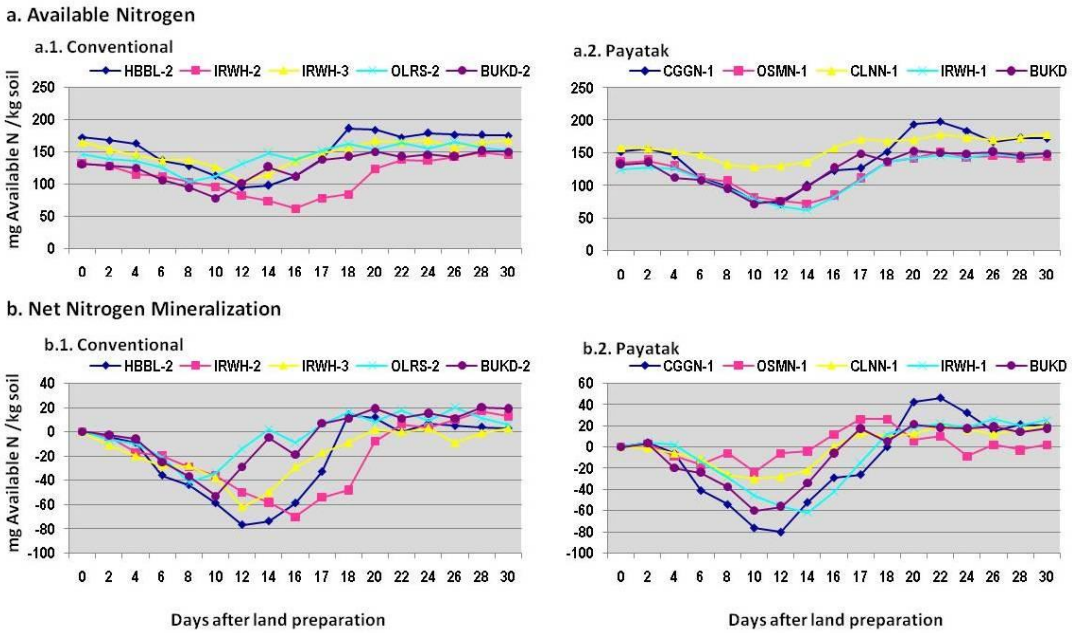

Figure 1. Available N and net N mineralization in conventional and payatak paddy within 30 days from the start of land preparation. Day 0: Land preparation starts; Day 8: 1st harrowing; Day 17: 2nd harrowing, Day 19– Transplanting.

preparation until the 18th day while in conventional system, it occurred from the start of land preparation until 18-20 days after. Highest immobilization was observed at 10-12 days after land preparation.

Soil Enzyme Activities and Microbial Activities: Soil enzyme activities were strongly influenced by rice farming systems as exhibited by highly significant T-test values (Table 5). The acid and alkaline phosphatases, dehydrogenase, and arylsulfatase activities in "payatak" fields were higher compared to those soils collected from conventional farms. The urease activity was higher in conventional soils compared to payatak soils. The microbial activity as estimated by FDA hydrolysis and *p*-D-glucosadase activities were higher in payatak soils compared to the conventional rice paddy soils.

Soil Microbial Functional Diversity and Community Structure: The Shannon-Weaver index of microbial functional diversity was higher in conventional rice field compared to those from the Payatak system (Table 6). The richness of substrate utilization and the Average Well Color Development (AWCD) were higher in "payatak" compared to those obtained from the conventional paddy soils (Table 6).

PCA analysis generated 2 principal components that would explain the majority of the variations on the substrate utilization profile of soil microorganisms. The 1st and the 2nd component extracted in PCA explained 58.2 and 32.2% of the data variance, respectively (Figure 2). The Bi-plot of PC1 and PC2 discriminated the samples from each other. Samples collected from rice fields under the "payatak" system are clustered toward the quadrant 1 while the soils collected from conventional rice fields are clustered in quadrant 3.

Correlations of Soil Microbial Properties with Enzyme Activities: In Table 7, the PC1 was positively correlated with acid phosphatase, alkaline phosphatase, dehydrogenase, FDA hydrolysate, *p*-D-glucosidase, and exchangeable K at 5% level but showed negative correlation with soil OM and pH. The PC2 was also positively correlated with acid phosphatase, alkaline phosphatase, dehydrogenase, FDA hydrolysis, *p*-D-glucosidase, available P and

Table 5. Enzyme activities in soils collected from payatak and conventional paddy soils in Catubig Valley.[a]

Sampling	Acid phosphatase		Alkaline phosphatase		Dehydrogenase		Arylsulfatase		FDA hydrolyses		p-d-glucosadase		Urease	
Site	CON	PYT	CON	PYT	CON	PYT	CON	PYT	CON	PYT	CON	PYT	CON	PYT
CGGN	435±20	620±21	531±21	642±20	193±10	285±12	72±10	44±10	34±4	52±4	42±2	50±2	53±4	45±2
OSMN	380±14	634±20	460±25	589±24	129±12	165±14	65±14	48±6	36±6	48±4	36±4	52±4	56±6	42±1
CLNN	320±18	681±24	387±23	681±28	142±14	212±18	64±12	44±8	32±4	46±3	34±2	46±4	42±2	33±2
MGTD	280±12	689±23	339±24	689±25	108±18	193±15	59±14	42±10	34±6	42±2	37±2	46±2	48±4	38±2
HBBL	412±22	580±12	499±22	632±26	140±15	177±14	64±14	36±6	32±2	39±2	34±4	44±2	46±2	40±1
ANGO	385±17	490±18	466±18	534±18	130±12	150±16	58±10	38±8	28±2	40±3	35±2	51±4	42±2	38±2
IRWH	284±18	485±16	344±20	529±19	96±10	148±16	64±10	32±8	32±3	46±2	38±1	50±6	44±2	36±0
OLRS	278±14	520±20	336±19	567±10	94±14	159±18	60±16	34±6	36±1	44±4	38±2	48±2	46±0	37±1
Mean	346.8	587.4*	420.2	607.9*	129	186.1*	63.2	39.8*	33	44.6*	36.8	48.4*	47.1	38.6*
Range:														
Max	435	689	531	689	193	285	72	48	36	52	42	52	56	45
Min	278	485	336	529	94	148	58	32	28	39	34	44	42	33

[a] Data are the average±standard deviation in each sampling site. CON is Conventional and PYT is payatak. * In the payatak column would indicate significant difference against the conventional column within the same site by *t*-test at 5% level.

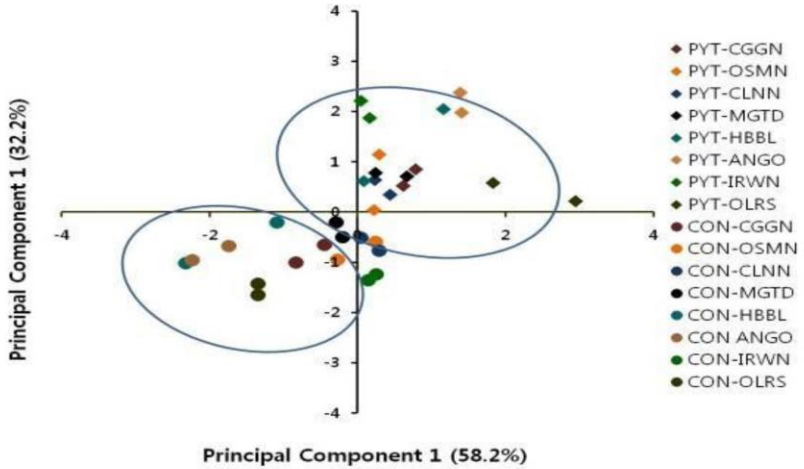

Figure 2. Bi-plot of PC1 and PC2 of the Biolog EcoPlate ™ readings at 72 hours of soils collected from payatak (PYT), and conventional (CON) rice fields.

Table 6. Shannon diversity index, carbon utilization richness and AWCD of Biolog Ecoplate™ data of soils collected from conventional and Payatak Paddy soils from Catubig, Valley.[a]

Sampling site (n= 4)	Shanon index		Richness		AWCD	
	CON	PYT	CON	PYT	CON	PYT
CGGN	12	8	19	24	1.09	1.30
OSMN	13	10	19	23	1.10	1.04
CLNN	16	13	17	23	0.93	0.99
MGTD	17	11	11	22	0.41	1.18
HBBL	23	10	8	23	0.33	1.21
ANGO	18	6	16	27	0.90	1.56
IRWH	16	13	16	20	0.62	0.95
OLRS	12	7	19	25	1.12	1.47
Mean	15.99	9.74*	15.31	23.13*	0.81	1.21*
Range:						
Max	23.11	12.98	19.00	26.50	1.12	1.56
Min	11.70	5.94	7.50	20.00	0.33	0.95

[a] Data are the average±standard deviation in each sampling site. CON is Conventional and PYT is payatak.
* In the payatak column would indicate significant difference against the conventional column within the same site by *t*-test at 5% level.

Table 7. Correlation analysis of Biolog Ecolate™ microbial community physiologic parameters with soil properties and enzyme activities.[a]

Soil properties	PC1	PC2	Shanon-Weaver index	Substrate utilization richness	AWCD
Enzyme activities					
Acid phosphatase	0.735**	0.697**	-0.582**	0.724**	0.491 ns
Alkaline phosphatase	0.753**	0.691**	-0.594**	0.724**	0.532*
Dehydrogenase	0.690**	0.550*	-0.563*	0.669**	0.590*
Arylsulfatase	-0.663**	-0.860**	0.553*	-0.692**	-0.497*
FDA hydrolyses	0.745**	0.589*	-0.720**	0.821**	0.595*
p-d-glucosadase	0.755**	0.721**	-0.810**	0.853**	0.626**
Urease	-0.543*	-0.753*	0.340 ns	-0.576*	-0.280 ns
Soil chemical properties					
pH	-0.379 ns	-0.575*	0.564*	-0.35 ns	-0.253 ns
EC (dS m^{-1})	-0.297 ns	-0.192 ns	0.536*	-0.30 ns	0.529*
Organic matter (g kg^{-1})	-0.588*	-0.586*	0.408 ns	-0.552*	-0.375 ns
Total N (%)	-0.562*	-0.585*	0.563*	-0.556*	0.565*
Available P (mg kg^{-1})	0.380 ns	0.565*	-0.523*	0.565*	0.646**
Exchangeable bases					
K	0.633**	0.808**	-0.468 ns	0.633**	0.435 ns
Ca	-0.167 ns	-0.314 ns	0.169 ns	-0.059 ns	-0.173 ns
mg	-0.080 ns	-0.042 ns	-0.189 ns	0.017 ns	0.135 ns
Na	-0.481 ns	-0.367 ns	0.569*	-0.508*	-0.445 ns
Total	-0.123 ns	-0.232 ns	0.090 ns	-0.003 ns	-0.108 ns

[a] PC1= Principal Component 1; PC2= Principal Component 2, ns= Not significant. ** Significant at 1%, * Significant at 5%.

exchangeable K at 5% level and showed negative correlation with soil OM, total N and soil pH. Shannon-Weaver indices were negatively correlated with acid phosphatase,alkaline phosphatase, dehydrogenase, FDA hydrolysis, *p*-D-glucosidase, and available P; and this is positively correlated with arylsulfatase, soil pH, *EC*, total N and exchangeable Na.

The carbon utilization richness showed the same results with that of PC1 except for positive correlation with available P and negative correlation with exchangeable Na. The AWCD is positively correlated with alkaline phosphatase,

dehydrogenase, FDA-hydrolysis, *p*-D-glucosidase, *EC*, total N and available P but negatively correlated with arylsulfatase.

DISCUSSION

This study seeks to understand the chemical and microbial properties of paddy soil under payatak and conventional rice farming and the relationship of these properties to nutrient dynamics and its implication to identifying appropriate farming practices for sustainable farming. The observed differences in the properties between these two rice farming systems could be attributed to the long term influences of the distinct practices employed. For example, payatak rice fields have long fallow period, limited nutrient inputs and devoid of constructed dikes to contain water and do not prevent high surface soil erosion during land preparation and early growth stage of rice plant. These field conditions promoted slow OM build up (due to higher OM matter decomposition and OM loss by surface erosion); high acidity due to internal acidification because of enhanced drainage and leaching of basic cations and buildup of organic acid with more advanced organic matter decomposition (Ulrich and Sumner, 2012); and low N content of payatak soils. Minimal nitrogen input which mostly come from carabao manure deposited during the fallow period and fewer dry matter (from weeds and other grasses) incorporated during land preparation also aggravated low N levels. In contrast, conventional paddy fields are usually subjected to prolonged submergence, frequent cropping and fertilization resulted in OM accumulation, higher N contents, soil pH and EC. Prolonged submergence retards organic matter decomposition and warrant buildup of OM (Sahrawat, 2003). Higher OM levels in paddy soils results in higher soil pH (Wang *et al.*, 2013) while higher EC could be attributed to accumulation of soluble salts due to frequent chemical fertilization (Behera and Shukla, 2015). Similarly, high OM leads to high N content of conventional paddy soils aside from the residual effect of nitrogen fertilization. In addition, payatak paddy soils contained higher available P and exchangeable K which could be attributed to less consumption of nutrients from soil as a result of less frequent cropping, and recycling of K from rice straw that are left in the field after harvest. On the other hand, high Na in conventional paddy soils could be due to frequent fertilizer application which could serve as an indication of problems on nutrient imbalance in the future (Vaneeckhaute *et al.*, 2013). Overall, the soil chemical properties and nutrient status would indicate that in payatak rice field, bunding and additional N sources especially organic fertilizers are options to improve soil fertility status of paddy fields in Catubig Valley.

One of the main differences between payatak and conventional rice farming system is in terms of the land preparation and the time lapse from land preparation to transplanting. Unlike conventional systems in which a 2 week-period is required before transplanting to facilitate the decomposition of freshly incorporated organic matter, the practice in payatak system involved transplanting immediately after soil puddling (trumping of weeds with the carabao carrying a weighted wooden harrow). The data on available N in soils have shown that N-immobilization occurred in both systems during the first 3 weeks after the onset of land preparation indicating similarities of available N dynamics. Highest immobilization occurred during the period of 10-12 days after land preparation due to changes of biochemical reactions to soil brought about by incorporation of weeds in the field before land preparation. Based on the N availability dynamics, transplanting immediately after puddling (usually 1-6 days after land preparation) should be avoided in payatak rice farming because the soil is undergoing high N immobilization which is detrimental to seedlings recovery. Seedlings transplanted immediately after incorporation of fresh farm residues will have poor seedling recovery due to poor N availability (Fageria and Oliveira, 2014) aside from the acid toxicity generated by active decomposition of freshly incorporated organic material into the soil (Nishikawa *et al.*, 2013). This could be the reason why seedling recovery in the "payatak" system was much later compared to the conventional system (data not shown).

Differences in the soil enzyme activities and Biolog EcoPlate data between payatak and conventional paddy soils represent the long term

influences of the distinct practices of different rice farming practices on soil biological properties and function. The Bi-plot and the subsequent correlations analysis showed that the principal component extracted after analysis could represent overall variation in the capacity of the microorganism for carbon substrate utilization and is related to several factors related to differences in chemical properties of the two rice farming systems. The PC1 was related to OM status of soil and exchangeable K that could trigger a distinct microbial community functional structure. On the other hand, variations due to PC2 could be attributed to differences in soil pH. Variations in soil pH, *EC*, and the amounts of nutrients have influenced the microbial functional diversity such as the Shannon-Weaver indices. The capacity of microorganisms to utilize different carbon sources, on the other hand was affected by OM levels, total N, and the concentration of K and Na in soil. On the other hand, payatak soils have higher enzymatic activities than conventional paddy soils which could be attributed to higher microbial activity and diversity as a result of fewer soil disturbances, infrequent submergence and higher substrate diversity incorporated into the soil under payatak system (Yang *et al.,* 2008). This could be an indication that the payatak farming system would enhance enzyme activity and is important for improving and maintaining soil fertility to ensure rice productivity (Wang *et al.* 2006). For example, the acid and alkaline phosphatase activities which are high in the payatak system may improve the P availability in soils. Dehydrogenase activity which is considered an important indicator of microbial activity in paddy soils revealed that the continuous use of the payatak farming system would result in an increase in its activity (Järvan *et al.,* 2014). The arylsulfatase activity which catalyses the hydrolysis of ester sulfatase to produce inorganic sulfate were higher in paddy soils under the payatak system. Its increase in activity could be due to enhancement of soil microbial activity towards the decomposition of organic materials rich in sulfur (Piutti *et al.,* 2015). Arylsulfatase is thought to play an important role in the mineralization of soil organic sulfur and supply of sulfate for growing plants (Balota *et al.,* 2014). These results would indicate that long term payatak and conventional rice farming systems would result in distinct microbial functional community which may affect the overall productivity and soil quality.

Overall, the results of our study revealed that there is a tendency to suffer nitrogen deficiency of the payatak system due to less build-up of OM but the system was able to maintain sufficient levels of phosphorus and potassium aside. On the other hand, the conventional system was able to build up OM in the soil due to high and frequent OM loading and slow decomposition rate as dictated by the anaerobic conditions. Based on our results, there are indications that payatak soil has better microbial properties than conventional paddy soil but it has limited nutrient content needed for optimum rice production, hence could not be considered an optimum farming practice for rice production. In order for payatak rice field to improve its productivity, farming practices and strategies that promote soil fertility buildup should be adopted. Strategies such as building and utilizing Soil Organic Matter (SOM) as opposed to using synthetic fertilizers, will improve soil fertility (Gattinger *et al.,* 2012), reduce nutrient losses (Syswerda *et al.,* 2012), and reduce global warming potential (Cavigelli *et al.,* 2013) while supporting similar crop yields to certain contexts (Seufert *et al.,* 2012) should be emphasized. Further study should be conducted to fully elucidate the impact of these two farming systems on soil quality and sustainability through the assessment of other soil quality parameters and its relation to nutrient availability and productivity over an extended period.

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در دسترس بودن مواد غذایی و ویژگی های بیولوژی خاک های برنجی تحت سیستم های کشاورزی سنتی Payatak در دره Catunig، فیلیپین

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چکیده

برای درک اثرات دراز مدت Payatak و سیستم معمولی کشت برنج بر ویژگی های خاک و کیفیت خاک، مطالع ای در حضور سیستم Payatak و سیستم معمولی کشت برنج سنتی در مزارع دره Catubig در شمال Samer فیلیپین انجام شد. تجزیه و تحلیل های شیمیایی نشان داد که خاک در سیستم Payatak بیشتر اسیدی است و محتوای OM، EC و N کمتری در مقایسه با خاک های تحت کشت سیستم معمول برنج دارد. اگرچه P و K در دسترس در خاک های Payatak بیشتر از خاک های سیستم معمول بود. N در دسترس به طورمعنی دار در زمان و منطقه نمونه برداری متفاوت بود و سطوح Nمعدنی در طول سه هفته بعد از آماده سازی زمین نوسان زیادی داشت. آنالیزهای BiologEcoPlate™ وتجزیه تحلیل های پس از آن نشان داد که ویژگی های بخشی از عملکرد جامعه میکروبی به فاکتورهای مختلفی مربوط می شوند که منجر به تفاوت هایی در خواص شیمیایی دو سیستم کشاورزی برنج می شود. . این نتایج به این معنی است که سطح OM و مقدار K قابل تبادل می تواند می تواند ساختار عملکردی متمایز میکروبی جامعه ایجاد کند. تغییرات در PH، EC و مقدار مواد مغذی خاک نیز باعث تغییر تنوع عملکردی میکروبی می شود که نشان دهنده همبستگی بین شاخص های شانون و ویور می باشد. به طور کلی، نتایج نشان می دهد که سیستم طولانی مدت "payatak" و سیستم معمول برنج ، باعث ایجاد شرایط

مختلف مواد مغذی و جامعه عملکردی متمایز میکربی می شود که ممکن است بر بهره وری کلی و کیفیت خاک تأثیر بگذارد. تجزیه و تحلیل بیشتر باید به منظور ایجاد رابطه بین ویژگی های میکروبی خاک بر بهره وری بلند مدت در خاک های برنج انجام شود.