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Soil Carbon Sequestration in Rice-Based Cropping Systems in Batac, Philippines

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ABSTRACT

This study focused on the assessment of capacity of farm soils to sequester carbon under different rice-based cropping patterns. The results of this study may be valuable for the formulation of soil and crop management for climate change mitigation in the agriculture sector in Ilocos Norte, Philippines. This study was conducted in major cultivated areas in the City of Batac, characterized by intensified and diversified cropping patterns centered around rice cultivation. A quantitative research design was employed to determine the different cropping patterns and their influence on soil organic carbon (SOC). The dominant cropping patterns observed in Batac City was rice, followed by any of the following crops; corn, shallot, eggplant, rice, tomato, pepper, garlic and tobacco. These cropping patterns are assumed to have an influence in soil pH, organic matter (OM), % carbon, phosphorus (P), potassium (K), bulk density, soil texture, moisture content, and soil carbon stock (SOC). Results showed that soil organic matter content in various cropping patterns was proportional to the soil carbon stock in the soil. The analysis of variance between cropping patterns exhibited high variability in OM and SOC with an F-value >1. Rice-tobacco exhibited the highest carbon stock (1.80%), while rice-garlic (0.63%) and rice-corn (0.60%) had the lowest. Understanding the influence of crop biomass and management through this study can be beneficial in the design of informed decision-making strategies and advocacy on cropping pattern management, which can be disseminated to farmers to enhance the carbon sequestration potential of agricultural lands.

HIGHLIGHTS

This study highlights the potential of agricultural soils to contribute to climate change mitigation through integrated crop and soil management practices.

1. INTRODUCTION

Soil organic carbon (SOC) plays a critical role in maintaining the global carbon cycle and climate regulation. Soil organic matter (SOM) is a major carbon pool that maintains global atmospheric carbon balance. Its decomposition contributes not only to the emission of greenhouse gases (GHG) into the atmosphere but also to the release of minerals that serve as nutrients for plant growth (PohankovÃ¡, et al., 2024). Approximately 12% of soil carbon is held in cultivated soils covering around 35% of the terrestrial land area of the planet (Haddaway et al., 2017). Intensive cropping and organic matter (OM) mismanagement have depleted organic carbon from agricultural soils, leading to land degradation (Adekiya et al., 2023) and enhanced greenhouse emission.

Sustainable agricultural practices have been proposed as a nature-based solution to address climate change and simultaneously combat soil degradation and food security issues by enhancing SOC sequestration in

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soils. Sustainable practices such as conservation agriculture have been demonstrated to improve soil physical, chemical, and biological properties that are important in maintaining soil health and ecosystem resilience (Francaviglia et al., 2023). The critical threshold of soil organic carbon (SOC) in the root zone ranges from 1.5% to 2.0%, influenced by land use, soil management, and farming techniques. Over half of the total Carbon (C) pool at a 1-meter depth is concentrated between 0.3 and 1 meter (Lal, 2004). Enhancing soil quality necessitates augmenting SOC concentration by implementing best management practices, such as conservation agriculture, which fosters a positive carbon budget (Buyanovsky and Wagner, 1998).

Majority of the agricultural practices contribute to SOC depletion while others support accumulation. Farm practices like tillage, crop residue management, and land use changes play a significant influence in determining the SOC levels. In the Philippines, crop diversification is encouraged as part of the climate-resilient agriculture (CRA) initiative to increase productivity, enhance resilience, and remove/reduce greenhouse gases (GHGs) (Dikitanan et al., 2017). These community strategies can be strengthened to increase knowledge and awareness to create information for local mitigation and adaptation planning.

The flat regions of Ilocos Norte undergo heavy farming, whereas the hilly and elevated areas are less utilized. The province, including the City of Batac is characterized by rice-oriented farming practices. Rice is usually grown in the wet season (June-October), while a variety of crops are planted in the dry season, such as corn, tobacco, garlic, eggplant, pepper, tomato, and onion. With climate change increasing the severity of typhoons and other natural disasters such as drought in the province, it is essential to assess the SOC levels of the main rice-based cropping systems in Batac City to determine the carbon sequestration potential of the agricultural land in the local area. Although intensive cultivation is known to result in a 25 to 75% less SOC than their counterparts in undisturbed ecosystems, long term rice cropping systems can significantly increase SOC stock due to high crop biomass production and decomposition rates resulting from extended submergence (Valenzuela-Balcázar et al., 2022).

The significance of this study lies in its potential to enhance soil fertility, structure, and crop yields, fostering favorable conditions for cultivation and carbon sequestration. Carbon is vital for sustaining life on Earth, supporting biological activity, diversity, and ecosystem productivity. The abundance of organic matter and associated soil biological populations stemming from diversified crop rotations enhances soil health and vitality. It is, therefore, imperative to know the capacity of the soil to sequester carbon under different rice-based cropping patterns. Specifically, this study aimed to (1) identify the rice-based cropping patterns in the City of Batac; (2) determine the influence of the different crop management practices on SOC; (3) determine the influence of cropping pattern on the soil characteristics; and (4) determine the relationship between physical properties, organic matter, and soil organic carbon under the different rice cropping patterns.

2. METHODOLOGY

2.1 Study site

The City of Batac is situated in the central-southwestern region of Ilocos Norte. It covers a total land area of 16,101 hectares with terrain varying from gently flat to rolling and hilly, with some areas being very steep. The City of Batac experiences a warm climate with two distinct seasons: the wet season, spanning from the latter part of May to October, characterized by an annual average rainfall exceeding 2,000 mm, and the dry season from November to April. It has a total cultivated land area of 2,063.65 ha, and the agricultural production system is characterized by intensive and diversified cropping patterns centered around rice cultivation. Figure 1 illustrates the sampling sites representing eight different cropping patterns.

2.2 Research design

This study employed a quantitative, field-based research design to measure the variables and test the hypotheses on the relationship among different variables through correlation and regression analyses. Additionally, a qualitative approach was used to determine the cropping practices used by the farmers. A purposive sampling method was employed and considered the largest cultivated farm areas in three major barangays as the sampling sites for this purpose.

Secondary data were also collected from the City Agriculture Office for data collection on major crops planted, classification of the cropping patterns employed by farmers within the three major barangays with the largest cultivated areas in the City of Batac.

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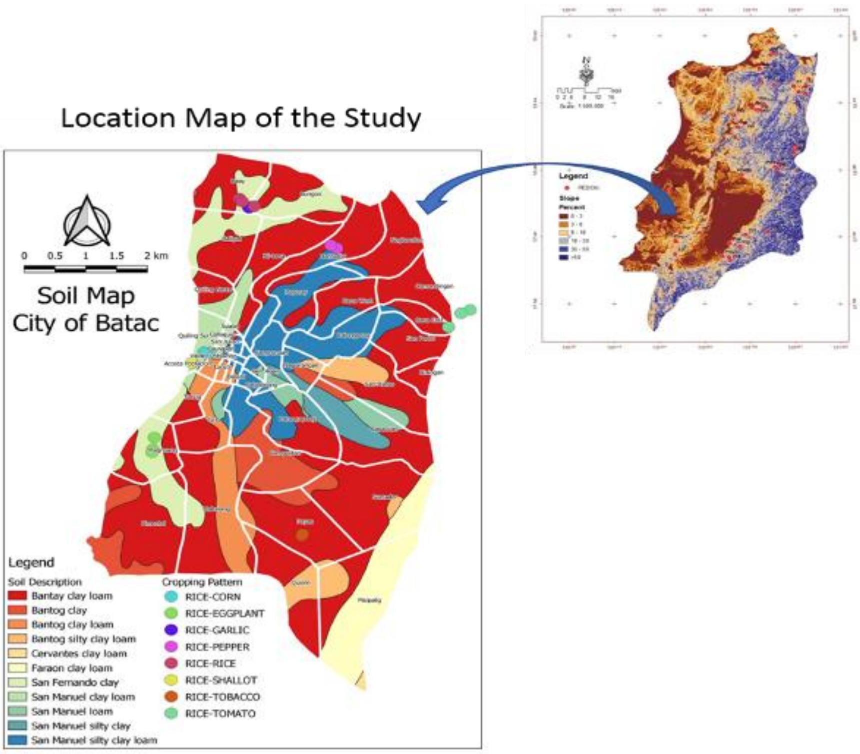

Figure 1. Study area of this study

2.3 Population and sample

This study considered 24 farmer respondents to obtain information needed to supplement the data obtained from the City Agriculture Office. A questionnaire designed to collect details on crop and farm management practices was used to obtain information from the farmers. For ethical purposes, the questionnaire survey was evaluated and approved first by the University Research Ethics Review Board (URERB) prior to the conduct of the survey.

The data on soil characteristics were obtained from 24 sampled farms (three farms for each cropping pattern) with distinct cropping patterns. Soils were collected from surface up to 30 cm in depth with three replicates per cropping type. Composite soil samples for each cropping pattern were employed for the soil analysis.

2.4 Research instrument

Information about the management practices implemented by the farmers was collected using a survey questionnaire.

2.5 Data gathering procedure

To accurately assess the physical and chemical attributes of the area, a composite sampling technique was utilized. A total of one kilogram of soil was collected from the composite samples per farm with distinct cropping pattern, securely packed in plastic containers, and kept in an icebox.

After collection, the soil samples were transported to the laboratory and subjected to air-drying. Following the drying process, the samples were ground and sifted through a soil sieve with a mesh size of 2 mm. The finely ground samples were then carefully stored in labeled plastic bags.

The following parameters were gathered with their corresponding procedures:

(1) Bulk density

Bulk density is an indicator of soil compaction. Bulk density is commonly determined using the core cylinder method (FAO, 2023). This method uses a core cylinder with a known volume. The core sampler was carefully inserted into the soil using a hammer to prevent compression. Subsequently, the samples were oven-dried at a temperature between 105°C and 110°C for one to three days, or until a constant dry weight was reached.

The bulk density was calculated by dividing the dry weight of soil by volume of the cylinder denoted in g/cm^3, as illustrated below:

$$\text{Bulk Density} = \frac{\text{Weight of ovendry soil (g)}}{\text{Volume of the sample}}$$

To calculate the volume, measurements of the core sampler's height and diameter were measured, and the volume was determined using the following formula:

$$V = \pi r^2 h$$

(2) Soil pH

Soil pH was determined using the soil-water slurry method. A 20 g soil sample was placed into a 100 mL beaker, and 20 mL of distilled water was added. The mixture was stirred at 20-minute interval over the course of an hour. Before the pH reading was obtained, the sample was thoroughly mixed.

(3) Soil organic matter content

The Walkley-Black Method (FAO, 2019) was selected due to the characteristics of the soil samples. The colorimetric method was employed since the soil samples exhibited a neutral to alkaline pH.

(4) Soil texture

Soil texture was determined by separating the different soil particle size fractions of sand, silt, and clay using the sieve method. Each separated particle was weighed, and the percentages were calculated.

(5) Soil potassium

The amount of potassium was determined using the standard Flame Photometry method. Available potassium in the soil was extracted and this solution was sprayed into the flame three times and the galvanometer readings were recorded. Distilled water was sprayed every after each sample to attain constant readings on galvanometer and readjusted to zero.

(6) Soil phosphorous

The analysis of soil phosphorus utilized the Modified Truog method, which involves the extraction of adsorbed phosphate from the soil using a specific solution. Within an acidic environment, soluble orthophosphates interact with molybdates, resulting in the formation of heteropoly molybdophosphoric acid. The intensity of color developed through this reaction is directly proportional to the amount of phosphates in the soil (Truog, 1930).

(7) X-ray fluorescence (XRF) analysis

X-ray fluorescence analysis is an analytical technique that uses the interaction of X-rays with a material to determine its elemental composition. Dried, ground soil samples were sieved to reduce particle size. A representative portion was placed in a sample cup and then irradiated with X-rays. The emitted X-rays were detected by the instrument and their energy frequencies are analyzed for the determination of the elemental composition. The standard procedure used by this study was based on the manufacturer's instructions for the benchtop XRF analyzer.

(8) X-ray diffraction (XRD) analysis

The XRD analysis was used to identify the mineral composition of the soil samples collected from the different farms. The samples were analyzed using an Olympus BTX (Laue method) with Cu kα metal target and 2 theta from 0 to 55 degrees. Phase identification was carried out using the match computer program and using the principle of the Hanawalt method.

(9) Determination of organic carbon per hectare

Determining soil bulk density readings is essential for computing the soil weight and quantifying soil organic carbon (SOC) stocks in tons per hectare. This computation used the formula outlined by the Agriculture and Food Division of the Department of Primary Industries and Regional Development in Australia (Hoyle and Murphy, 2018).

$$\text{Soil Weight per Ha} = 10{,}000\,\frac{\text{m}^2}{\text{ha}} \times \text{soil depth} \times \text{bulk density}$$

$$\text{Soil Carbon Stock}\,\frac{\text{kg}}{\text{ha}} = \text{Soil carbon} \times \text{soil depth} \times \text{weight of soil per hectare}$$

2.6 Data analysis

The collected data were compiled and subjected to analysis of variance using STAR 2.0 v.1. Variations in means were assessed through the honestly significant difference (HSD) test at a significance level of 0.05 ($HSD_{0.05}$). Additionally, correlation and regression analyses were conducted using SPSS software to ascertain the connections and associations among the parameters.

3. RESULTS AND DISCUSSION

3.1 Major rice-based cropping patterns in the City of Batac

According to the City Agriculture Office of Batac City, approximately 2,053.65 ha are utilized for rice cultivation during wet season while various vegetables and other high-value crops are grown in the dry season. Table 1 shows the area planted with rice and other crops, along with the total of 5,193 farmers. The city adheres to 13 distinct cropping patterns, among which the predominant ones include rice-corn (1,497.45 ha), rice-tobacco (374.74 ha), rice-rice

(115.62 ha), rice-mungbean (53.91 ha), rice-garlic (41.10 ha), rice-eggplant (29.15 ha), and rice-shallot (14.68 ha). The rice-corn cropping pattern holds the largest area and engages the highest number of farmers, largely due to the support from the Department of Agriculture and the *cornick* industry. Conversely, the rice-tomato cropping pattern ranked last, as tomato is no longer a profitable crop to farmers because of the closure of the National Food Corporation known for tomato paste production.

Table 1. Cropping pattern and the number of farmers being engaged in 2020-2021.

Cropping pattern	Area (planted/ha)	Number of growers
Rice-Corn	1,497.45	3,637
Rice-Tobacco	274.74	593
Rice-Rice	115.62	316
Rice-Mungbean	53.91	288
Rice-Garlic	41.10	173
Rice-Eggplant	29.16	96
Rice-Shallot	14.68	62
Rice-Pepper	10.63	45
Rice-Squash	5.00	26
Rice-Stringbean	4.97	26
Rice-Ampalaya	3.63	23
Rice-Okra	1.24	5
Rice-Tomato	1.22	4
Total	2,053.65	5,193

Source: City Agriculture Office, City of Batac

3.2 Crop management practices

Table 2 assesses various crop management practices across different cropping patterns. The findings reveal that respondents follow the rice-rice, rice-pepper, and rice-eggplant cropping patterns integrated the use organic fertilizer. Conversely, rice-garlic and rice-tomato crops are treated with complete ammonium and sulfate fertilizer. At the same time, respondents engaged in rice-corn, rice-tobacco, and rice-shallot patterns do not apply fertilizer prior to planting. Nearly all participants apply urea, complete fertilizer, and sulfate fertilizers to their crops during the cropping period. With regards to pesticide use, all the respondents apply insecticides and fungicides to control insect pests and diseases. The application of fertilizer affects soil's ability to accumulate soil organic matter. On the other hand, continuous cropping and integrated use of organic and inorganic fertilizers increases soil C sequestration and crop yields (Brar et al., 2015) and several studies have proven that organic amendments improve soil fertility. In the study of Qui (2024), it was plausible that the stimulatory effect of the organic amendments on rice yield and above-ground dry biomass resulted at least partly from the increased availability of plant nutrients. Cropping pattern also influence soil properties. The impacts of cropping patterns are observed in the soil surface where crop residues are accumulated, and to the depth where tillage is exerted, as soil organic matter is highly dependent on the decomposition of crop residue (Gikonyo et al., 2022).

3.3 Soil physical characteristics under different cropping pattern

Soil physical properties are important in crop production due to their influence on root development, water accessibility, nutrient availability, and overall plant well-being. Furthermore, they affect nutrient cycling mechanisms within the soil, notably in the accumulation of organic matter. The physical attributes of soil also influence the availability, retention, and discharge of nutrients derived from organic matter. Soils the posses favorable structural characteristics contribute to effective nutrient cycling, ensuring that organic matter contributes to the nourishment essential for plant growth (Blanco-Canqui et al., 2009).

Table 2. Crop management practices of the different cropping patterns

Cropping pattern	Crop management practices				
	Code #	Rice-based	Fertilizer added before cropping	Fertilizer added during cropping	Pesticide used during cropping
Rice-Corn	1	√	None	Urea	Round up
	2		None	Urea	Round up
	3	√	None	Urea	Round up
Rice-Garlic	4	√	Complete, $NH_4^+$and SO_4	None	Insecticide and Boulder
	5	√	Complete, $NH_4^+$and SO_4	None	Insecticide and Boulder
	6	√	Complete, $NH_4^+$and SO_4	None	Insecticide and Boulder
Rice-Rice	7	√	Organic fertilizer	Urea and complete	Brodan and Magnum
	8	√	Organic fertilizer	Urea and complete	Brodan and Magnum
	9	√	Organic fertilizer	Urea and complete	Brodan and Magnum
Rice-Pepper	10	√	Organic fertilizer	Urea, sulfate and complete	Brodan
	11	√	Organic fertilizer	Urea, sulfate and complete	Brodan
	12	√	Organic fertilizer	Urea, sulfate and complete	Brodan
Rice-Tobacco	13	√	None	Urea	Brodan
	14	√	None	Urea	Brodan
	15	√	None	Urea	Brodan
Rice-Tomato	16	√	Complete	Urea	Lanid
	17	√	Complete	Urea	Lanid
	18	√	Complete	Urea	Lanid
Rice-Eggplant	19	√	Organic fertilizer	Complete	Magnum and Alika
	20	√	Organic fertilizer	Urea and complete	Gold
	21	√	Organic fertilizer	Urea and complete	Gold
Rice-Shallot	22	√	None	Urea and complete	Fungicide
	23	√	None	Urea and complete	Fungicide
	24	√	None	Urea and complete	Fungicide

Table 3 presents the soil physical properties of selected cropping patterns investigated in this study. Soil texture was determined based on the relative proportions of three distinct soil particles: sand, silt, and clay. The analysis of variance results indicated significant variations (p=0.01) among the observed soil physical properties. The highest percentage of clay content was found in the rice-rice cropping pattern at 46.20%, followed by rice-garlic at 38.67%. Other cropping patterns showed similar clay contents ranging from 3.37% to 6.03%.

On the other hand, the rice-eggplant cropping pattern exhibited the highest percentage of silt at 32.53%, followed closely by rice-corn, rice-rice, and rice-garlic patterns with 29.07%, 28.60%, and 27.07% respectively. These values were comparable to the rice-pepper pattern at 23.33%. The rice-pepper pattern was similar to rice-shallot and rice-tobacco patterns, with silt contents of 20.40% and 20.27%, respectively.

Furthermore, the highest percentage of sand was found in the rice-tobacco and rice-shallot patterns at 74.77% and 74.24%, respectively, closely followed by the rice-tomato pattern at 72.47%. Rice-garlic and rice-rice patterns had the least sand content, with 34.27% and 25.20% respectively.

Bulk density of soil is influenced by various factors, including clay content, land use, and management practices (Chaudhari et al., 2013). Similarly, sand content has a more significant effect on soil bulk density than other soil properties (Ahad et al., 2015). Similar trends were observed in the bulk density values derived from the soil with varying cropping patterns. In this study, cropping patterns with higher sand content exhibited greater soil bulk density. In the current study, the highest bulk density values were observed in cropping patterns rice-corn, rice-pepper, rice-tomato, rice-shallot, rice-eggplant, and rice-tobacco, all with comparable results. Conversely, the lowest bulk density values were found in the rice-garlic and rice-rice cropping patterns, characterized by clayey-textured soil, with 1.28 g/cm^{-3} and 1.30 g/cm^{-3}, respectively.

Table 3. The soil physical properties under the different cropping patterns

Cropping pattern	Soil physical properties				
	% Clay	% Silt	% Sand	Soil texture	Bulk density
	**	**	**	**	**
Rice-Corn	5.60^{c}	29.07^{ab}	65.33^{c}	Sandy loam	1.43^{a}
Rice-Garlic	38.67^{b}	27.07^{abc}	34.27^{d}	Clay loam	1.30^{bc}
Rice-Rice	46.20^{a}	28.60^{abc}	25.20^{e}	Clay	1.28^{c}
Rice-Pepper	6.03^{c}	25.57^{bcd}	68.40^{bc}	Sandy loam	1.41^{a}
Rice-Tobacco	4.97^{c}	20.27^{d}	74.77^{a}	Sandy loam	1.36^{ab}
Rice-Tomato	4.20^{c}	23.33^{cd}	72.47^{ab}	Sandy loam	1.41^{a}
Rice-Eggplant	3.37^{c}	32.53^{a}	64.10^{c}	Sandy loam	1.37^{ab}
Rice-Shallot	5.37^{c}	20.40^{d}	74.24^{a}	Sandy loam	1.41^{a}
CV (%)	14.23	7.59	3.00		2.14

**=Significant at 1% level; CV=coefficient of variation; Means with the same letter are significantly different at 1% level of significance using HSD Test.

3.4 Soil chemical properties under the different cropping patterns

The soil chemical properties significantly influence the accumulation of organic matter in the soil. Properties like pH, redox potential, and nutrient content directly impact the transformation of organic matter retained in the soil. Sufficient nutrient availability is essential for the decomposition of organic matter. Microorganisms engaged in the breakdown of organic substances require vital nutrients like nitrogen (N), phosphorus (P), and potassium (K) to fuel their metabolic processes. The activity and efficiency of microbial decomposition and the subsequent accumulation of organic matter are influenced by soil pH (Blanco-Canqui et al., 2009). Table 4 reveals the influence of chemical soil properties on the formation and accumulation of SOC. Among the cropping patterns, rice-shallot and rice-corn showed the highest and are significantly different (P) content in the soil. This higher P content is attributed to the crop management, where P application is more to enhance bulb production and robust crop growth. However, the potassium content of soils across the various cropping systems did not exhibit significant differences. Generally, N, P, K and macronutrients are needed by microorganisms in the soil to enhance the decomposition of organic matter and the formation of stable carbon compounds (Zhou et al., 2025).

The soil pH of the distinct cropping patterns also displayed significant variations. The results indicated that rice-corn, rice-garlic, rice-rice, and rice-pepper patterns were characterized by neutral pH, while the remaining cropping patterns featured slightly acidic soils. It is worth noting that soil pH affects microbial activity and the composition of microbial communities. Different microbial groups exhibit preferences for specific pH levels. Soil chemical attributes influencing pH levels can impact the abundance and activity of microorganisms in the decomposing organic matter. An optimal pH range, particularly a neutral pH, can stimulate microbial activity and enhance the breakdown of organic matter. Research has underscored that soil organic matter (SOM) associated with the sand-size fraction is more susceptible to decomposition, leading to higher turnover compared to the silt- or clay-size fractions (Angers and Mehuys, 1990). Crop sequencing is one important management practice in agriculture as it helps to improve soil's physical texture by rotating different crops whose roots reach various soil depths. Crop rotation helps improve aggregate stability and water-holding capacity, decrease bulk density, and reduce soil compaction (Qui et al., 2024).

A notable difference in the build-up of organic matter content among various cropping patterns was noted in this study. The rice-tobacco cropping pattern exhibited the highest organic matter content (3.11%), followed by rice-eggplant (2.46%). This can be attributed to the crops' characteristics, primarily their broad leaves leading to a greater biomass contribution to the soil. Conversely, the rice-corn and rice-garlic cropping patterns displayed the lowest organic matter content, measuring 1.04% and 1.07%, respectively.

The organic carbon estimation was conducted based on the assumption that soil organic matter comprises 58% carbon, which applies to certain soils or specific components of soil organic matter (Pribyl, 2010). The results demonstrate a direct proportionality between organic carbon (OC) and organic matter (OM). As a result, the rice-tobacco cropping pattern exhibited the highest OC content at 1.80%, followed by rice eggplant at 1.43%. Conversely, rice-corn displayed the lowest OC content, accompanied by rice-garlic at 0.60% and 0.63%, respectively. The varying SOC in the soil under different crop patterns may be attributed to several factors such as crop and soil management. Crop rotation changes the amount and type of crop residues or root systems, which affects fixation, mineralization, and the total amount of soil organic carbon that a soil contains (Niu et al., 2024) while mineral and organic fertilization significantly enhance SOC quality and quantity in the soil (Zhange et al., 2024).

3.5 X-ray fluorescence (XRF) analysis

XRF analysis revealed the elemental composition of the soil samples under different cropping patterns. Figure 2 reveals that soil samples are Si-rich with significant amount of iron and aluminum with at least 60% light elements. Other inorganic ions such as magnesium, calcium, titanium and manganese were also detected. It can be noted that the soil samples for rice-onion cropping pattern have trace amounts of phosphorous.

Table 4. The soil chemical properties under the different cropping patterns

Cropping pattern	Soil chemical properties				
	% OM	% OC	P (ppm)	K (ppm)	pH
	**	**	**	ns	**
Rice-Corn	1.04[e]	0.60[e]	161.77[b]	268.26	7.00[a]
Rice-Garlic	1.07[de]	0.63[de]	61.50[d]	210.79	7.00[a]
Rice-Rice	1.33[cde]	0.77[cd]	54.16[d]	223.47	7.00[a]
Rice-Pepper	1.33[cd]	0.77[cd]	122.54[c]	225.83	7.03[a]
Rice-Tobacco	3.11[a]	1.80[a]	72.11[d]	247.06	6.87[a]
Rice-Tomato	1.57[c]	0.91[c]	46.56[d]	257.62	6.80[ab]
Rice-Eggplant	2.46[b]	1.43[b]	126.62[bc]	222.95	6.57[b]
Rice-Shallot	1.34[cd]	0.78[cd]	293.30[a]	265.82	6.80[ab]
CV (%)	5.96	5.90	11.11	8.68	1.25

**=Significant at 1% level; ns=not significant; CV=coefficient of variation; Means with the same letter are significantly different at 1% level of significance using HSD Test.

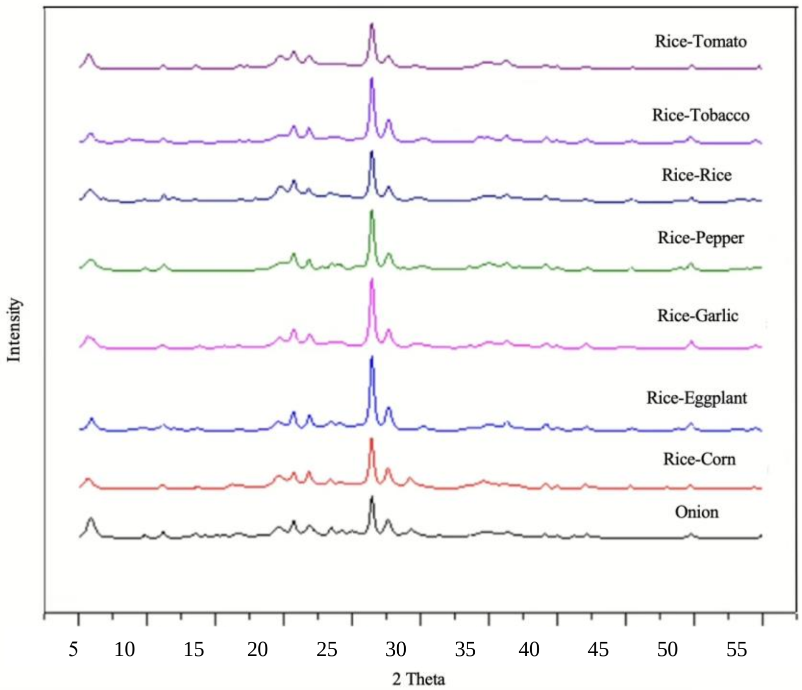

Figure 2. X-ray fluorescence analysis of soils under different cropping patterns in the City of Batac

The silicon-to-aluminum (Si/Al) ration was consistent across all samples, with an average of approximately 3.0 (Table 5). From an environmental standpoint, a high Si/Al ratio in soils or minerals significantly influences soil stability and water retention. Such soils often demonstrate greater structural stability and increased water-holding capacity, supporting plant growth and reducing erosion risk.

Similarly, the iron to aluminum (Fe/Al) ratio was consistent across all samples averaging at approximately 1.0. This consistency suggests the presence of substantial quantities of Fe-Al smectite minerals in the soil. Smectite minerals are known for their high cation exchange capacity (CEC), enabling them to retain and exchange essential nutrients such as calcium (Ca), magnesium (Mg), potassium (K), and sodium (Na). This property directly influences nutrient availability and overall soil fertility. Additionally, the expandable lattice structure of smectite-rich soils enhances water retention, which is particularly advantageous for plant growth in dry conditions. The presence of these minerals underscores the soil's capacity to support sustainable agricultural productivity.

Table 5. The chemical composition of soil based on the ratio of its components

Cropping pattern	Si/Al ratio (ppm)	Fe/Al ratio (ppm)
Rice-Shallot	3.45	1.14
Rice-Eggplant	3.21	1.22
Rice-Tomato	3.12	1.13
Rice-Tobacco	3.28	1.09
Rice-Sweet Pepper/Chili	3.13	1.07
Rice-Rice	2.95	1.0
Rice-Corn	3.27	1.09
Rice-Garlic	3.24	0.99

Minerals with higher Si/Al ratios may contribute to soil stability and water-holding capacity. Similarly, a consistent iron to aluminum ration of about 1.0 was observed in the samples. This ratio suggests the presence of significant amounts of Fe-Al smectite minerals in the soil. Smectite minerals are characterized by a high cation exchange capacity (CEC), facilitating the exchange of vatious positively charged ions (cations) such as calcium (Ca), magnessium (Mg), potassium (K), and sodium (Na). Thus, this affect nutrient availability in the soil. Smectite-rich soils have good water retention capabilities due to their expandable lattice structure, which can swell and hold water. This characteristic benefits plants by improving moisture retention during dry periods (Kumarti and Mohan, 2021).

3.6 Soil weight and soil carbon stock of the different cropping patterns

Soil weight was assessed at a depth of 30 cm, and the determination of carbon stock in the soil for each cropping pattern was based on bulk density. Findings indicated that soils characterized by higher bulk density tend to exhibit greater carbon weight, ranging from 4,090 kg C/ha (rice-tobacco) to 4,280 kg C/ha (rice-corn), as detailed in Table 6. These cropping patterns were associated with sandy loam and loamy sand soil textures, which contributed to their higher bulk density and carbon value stocks.

In contrast, soils with a clay composition demonstrated notably lower weight, registering at 3,830 kg C/ha (rice-rice) and 3,900 C/kg ha (rice-garlic). These findings indicate that carbon stock is significantly influenced by the presence of soil organic matter within various cropping patterns. The rice-tobacco pattern exhibited the highest carbon stock at 2,215.32 kg C/ha, which was statistically distinct from the rice-eggplant pattern (1,757.16 kg C/ha) and rice-tomato pattern (1,155.10 kg C/ha. These patterns also exhibited a higher soil bulk density (sandy loam) as compared to the others. Conversely, the lowest carbon stocks were observed in the rice-garlic (725.27 kg C/ha), rice-corn (776.33 kg C/ha), and rice-rice (883.19 kg C/ha) patterns.

3.7 Correlation analysis of the various factors affecting soil organic carbon

The correlation analysis shown in Table 7 shows that the clay content has a strong negative correlation with organic matter (OM) and sand content, while showing a positive correlation with carbon and silt content. Sand content has a strong negative correlation with clay, while it has a positive correlation with organic matter and silt content. Bulk density (BD) has a strong negative correlation with clay and silt content, suggesting that higher clay and silt content lead to lower bulk density. Phosphorus (P) has positive correlations with clay, sand, and silt content, indicating that it is associated with higher proportions of these components. pH has a strong negative correlation with clay, organic matter, and carbon content, suggesting that higher proportions of these components lead to lower soil pH. These correlations provide insights into the relationships between different soil properties and can be useful in understanding soil composition and fertility.

Soil organic carbon (SOC) is a component of soil organic matter. Organic matter is primarily made of 58% carbon (Pribyl, 2010). Thus, the organic carbon in soil is directly proportional to the organic matter hence, rice-tobacco has the highest organic carbon at 1.80% followed by rice-eggplant at 1.43%. Accordingly, rice-corn obtain the lowest organic carbon followed by rice-garlic with 0.60% and 0.63%. The ability of the soil to store carbon is positively correlated with clay content since its larger surface area provides a protective environment against decomposition therefore increasing the capacity for carbon retention. Sand on the other hand, is inversely correlated soil carbon stock because sand has a lower capacity for carbon stabilization as compared to clay. Organic matter is the primarily source of carbon, thus, the higher the amount of OM, the higher the soil carbon stock.

Table 6. Soil weight and soil carbon stock of the different cropping patterns

Cropping pattern	Amount of carbon sequestered	
	WS (kg C/ha)	Carbon sequestered (kg C/ha)
	**	**
Rice-Corn	4,280^{a}	776.33^{e}
Rice-Garlic	3,900^{bc}	725.27^{e}
Rice-Rice	3,830^{c}	883.19^{de}
Rice-Pepper	4,220^{a}	978.65^{cd}
Rice-Tobacco	4,090^{ab}	2,215.32^{a}
Rice-Tomato	4,230^{a}	1,155.10^{c}
Rice-Eggplant	4,100^{ab}	1,757.16^{b}
Rice-Shallot	4,220^{a}	980.40^{cd}
CV (%)	2.14	5.36

Table 7. Correlation analysis

	CP	Clay	Silt	Sand	OM	C	WS	SC stock	P	K
Clay	-0.506*									
	0.012									
Silt	-0.343	0.234								
	1	0.27								
Sand	0.546**	-0.972**	-0.455*							
	0.006	<.001	0.025							
OM	0.453*	-0.384	-0.177	0.394						
	0.026	0.064	0.407	0.057						
BD	0.267	-0.837**	-0.245	0.825**	-0.023					
	0.207	<.001	0.249	<.001	0.916					
Carbon	0.453*	-0.384	-0.177	0.394	1.00**					
	0.026	0.064	0.407	0.057	0					
WS	0.267	-0.837**	-0.245	0.825**	-0.023	-0.023				
	0.207	<.001	0.249	<.001	0.916	0.916				
SC stock	0.475*	0.445*	-0.197	-0.455*	0.997**	0.997**	0.05			
	0.019	0.029	0.357	0.026	<.001	<.001	0.815			
P	0.410*	-0.419*	-0.201	0.433*	-0.2	-0.2	0.457*	-0.168		
	0.047	0.041	0.347	0.035	0.349	0.349	0.025	0.433		
K	0.165	-0.445*	-0.318	0.484*	-0.013	0.013	0.488*	0.023	0.433*	
	0.441	0.029	0.13	0.017	0.952	0.952	0.016	0.916	0.035	
pH	-0.706**	0.412*	-0.048	-0.366	-0.534**	-0.534**	-0.107	-0.543**	-0.193	-0.179
	<.001	0.046	0.825	0.079	0.007	0.007	0.619	0.006	0.367	0.402

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4. CONCLUSION

Based on the comprehensive analysis of the study's findings, several noteworthy conclusions can be drawn, shedding light on the intricate relationships between soil properties, cropping patterns, and carbon sequestration.

The rice-corn cropping pattern was found to be the most dominant followed by rice-tobacco, in the City of Batac, with the latter obtained as a higher carbon stock mostly attributed to greater biomass (broad leaf) and management practice after crop harvesting. Additionally, the commonly practiced cropping management by farmers include the use and application of fertilizer and pesticides in the crops.

This study reveals that cropping patterns influence in the clay, silt, and sand particles of the soil. Generally, cropping patterns with higher proportions of clay tended to exhibit lower bulk density and soil weight while those dominated by sand showed higher bulk density and soil weight. Moreover, the phosphorus content of the soil varied significantly across cropping pattern while potassium did not differ significantly. The soil organic content was highest in the rice-tobacco cropping pattern, attributed to the biomass contribution of broadleaf crops, while other patterns displayed varying levels. These findings highlight the potential for strategic cropping choices to enhance carbon sequestration, thereby contributing to climate change mitigation efforts.

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AUTHOR CONTRIBUTIONS

Conceptualization, Methodology, Validation, Supervision and Writing Original Draft Preparation, Formal Analysis, Data Curation, Visualization, Writing: Bucao and Gonzales Experimental run and Data Collection: Bucao, Gonzales, Bumanglag and Tapac; Review and Editing: Gonzales

DECLARATION OF CONFLICT OF INTEREST

The authors have no conflict of interest to declare.

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