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ORIGINAL ARTICLE

Greenhouse Gas Fluxes of Different Vegetation Cover in Bambanin Peatland, Victoria, Oriental Mindoro, Philippines during Wet Season

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Abstract: Peatlands are characterized by deep accumulation of partly decomposed organic materials called "peat" and are an important terrestrial carbon pool. Human interventions have drastically alter peatland ecosystems in many parts of the tropics. One negative impact of these activities is that peatlands become net sources of CO_2 emissions. The main objective of this study was to determine the level of emissions of peat-derived greenhouse gases (GHGs) namely, CO_2, CH_4 and N_2O across vegetation cover types during the wet season. Taking into consideration selected soil physico-chemical parameters and other environmental variables, the extent GHG fluxes in Bambanin peatland, Victoria, Oriental Mindoro, Philippines was investigated during wet season. Results revealed that the average CO_2 flux was highest in the forestland (151.91 Mg ha^{-1} yr^{-1}) as compared to cultivated land (86.71 Mg ha^{-1} yr^{-1}) and grassland (49.89 Mg ha^{-1} yr^{-1}) owing to low organic matter content and water table drawdown. The total estimated gross CO_2 flux was 2,544.69 Mg ha^{-1} yr^{-1} while relatively low amount of CH_4 (total of 6.98 Mg ha^{-1} yr^{-1}) and an almost negligible total N_2O emission (0.25 Mg ha^{-1} yr^{-1}) were also observed during the time of collection. Results of this study could be used in formulating mitigation policies particularly on the land use management that will address issues on peatland hydrology, agricultural activities and human encroachment to the protected area.

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1. Introduction

Peatlands are wetland ecosystems characterized by the deep accumulation of partly decomposed organic materials called "peat" (Vitt, 2013) accumulated over thousands of years under waterlogged, acidic, nutrient poor and anoxic environment. Globally, about 8% of peatland areas are found in the tropics (Hergoualc'h & Verchot, 2014) mainly in Southeast Asia covering an area of approximately 29 million hectares. Philippines has a mean area of around 10,700 hectares (Page, Rieley, & Wüst, 2006).

Tropical peatlands are an important terrestrial carbon pool and account for one third of the world's soil C pool (Turetsky, Wieder, Halsey, & Vitt, 2002). However, human disturbances such as agriculture, human settlement, logging, land use changes, fires and drainage pose huge impacts to the peatland ecosystems (Dohong et al., 2017). Since this ecosystem is highly vulnerable to human intervention, they become source of carbon emissions (Murdiyarso et al., 2010) that contribute to global warming (Xu et al., 2018). GHG emissions of peatlands in the Philippines have yet to be studied. Some peatlands are alienable and disposal, some are titled which are at greater risk of unmanaged utilization. Research undertakings need to be done to gather significant data on peatland emission rates. Results of such studies may be used in formulating mitigation policies especially in restoring peatland hydrology to inhibit peat oxidation and widespread degradation of peatlands, hence, this study.

1.1 Objectives

The objectives of this study were as follows:

a. To determine the soil characteristics of the Bambanin peatland

b. To determine the soil carbon stock of the various land uses under study

c. To assess greenhouse gas emissions from different land uses during the wet season

2. Methodology

Data collection was conducted in November 2018 representing the wet season.

2.1 Site Description

Bambanin is a barangay in the municipality of Victoria, in the province of Oriental Mindoro with land area of 546.7 hectares (Barangay Profile, 2019). Victoria has a tropical climate. Its average temperature is 27.2 °C while the average annual rainfall is 2093 mm. March accordingly is the driest month with 39 mm of precipitation. The site receives the highest precipitation in July with an average of 288 mm. In the whole year, January has the lowest average temperature of 25.7°C. May, on the other hand, is the warmest month with an average of 28.6°C. (retrieved from https://en.climate-data.org). Figure 2 below shows the boundaries of Bambanin peatland.

Figure 2. Map showing the boundaries of Bambanin Peatland in Victoria,Oriental Mindoro

2.2 Soil quality assessment

Using a soil corer (auger), a depth of 2 meters from each vegetation cover/land use (grassland, forestland, cultivated land) with four replicates each was taken. The soil samples were divided into 0-30, 30-75, 75-100, 100-150 and 150-200 cm fractions (5 composite samples from each vegetation cover, n=15) for the measurements of soil chemical properties such as pH, NPK and organic matter. The samples were properly labelled and brought to ERDB Laboratory for analysis. Bulk density, soil moisture content and soil organic carbon (SOC) stocks were determined and associated it with the amount of GHG emitted by the soil to the atmosphere.

2.3 Assessment of in-situ and ex-situ gas emissions

Four permanent randomly selected measurement plots under each vegetation cover type were established at the site. Using an Automated Soil Gas Flux System (LI-8100A or LiCor), in-situ carbon dioxide (CO_2) fluxes from the different land uses were determined. Samples of other potent greenhouse gases such as CH_4 and N_2O were also collected for laboratory analysis.

The gas samples were extracted at time interval of 0, 5, 10, 15 and 20 minutes using a 60-ml plastic syringe. A total of 60 gas samples were collected and brought to Kenzo Hemmi Laboratory of the International Rice Research Institute (IRRI) for analysis. These samples were analyzed using a Gas Chromatography Unit (GC SRI 8610C), a multiple gas analyzer designed for the detection of carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O) with flame ionization detector (FID) and methanizer.

3. Results and discussions

3.1 Soil quality

Results showed that soil acidity was high in all sites as reflected in the low pH values that ranged from 4.3 to 5.5 (Table1). The observed pH values were moderately acidic (between 5.2-6.0) to strongly acidic (<5.1). Literature suggests that peatlands are characterized by low pH as well as low primary productivity (Turner et al., 2016).

Table 1. Average values for the soil physico - chemical properties across sites during wet season

Parameters	Ideal Range	Forestland	Cultivated	Grassland
pH		4.6-5.5	4.3-5.3	4.7-5.4
%N	2-5%	0.56	0.61	0.82
P (ppm)	40-60 ppm min	1.30	1.29	2.13
%K	1%	0.37	0.32	0.36
%OM	>12 %	11.25	12.14	16.44
%SOC		6.54	7.06	9.56
%Sand		68	66.8	82
%Clay		19.2	23.6	8.8
%Silt		12.8	9.6	9.2

It was observed that nitrogen (N) was highest (0.82) in grassland as compared to other land cover types within the peatland area. It was assumed that most mineralized N from soil under optimal growth conditions is used up by grassland soils (Deru et al., 2019). In addition, the amount of nitrogen in grassland soils increases logarithmically as moisture values increase. An increase in the moisture leads to surface soils' higher nitrogen and organic-matter content. Such relationship is particularly distinct in grassland soils (Jenny, 1941).

Phosphorus contents of soil samples in all sites were very low which ranged from 1.29-2.13 ppm. Such low levels of P in the samples could be attributed to low soil pH.

Similar to Nitrogen and Phosphorus, the amount of Potassium in soils was relatively low which was below the minimum plant requirement of 1%.

Organic matter was observed to be high even in this well-drained peatland. The very high level of organic matter for mineral soil is >6% while peat soil's OM level should be >15% according to Agvise Laboratories (Northwood, North Dakota). Most soil fractions across sites have OM level of more than 15% although by average, only the grassland soils meet this criterion. Results of this experiment (Appendix 1) showed that OM was highest in the undisturbed grassland area (16.44%) while OM content of the soils collected from crop/cultivated land (12.14%) was higher than that of the forestland (11.25%). This result was similar to a study on relative efficiency of roots and tops of plants in Nebraska (Kramer, 1956) where they revealed that grass soils are much richer in humus (organic component of soil) than the forest soil and that grasses produce more OM underground than aboveground.

Bulk densities (BD), the weight of the dry soil divided by the total soil volume (g/cm^3), of the different land uses (forestland = 0.23; cultivated land = 0.59 & grassland = 0.22) were fairly low although the soils were dominated by sandy particles. Peat's low bulk density ranges from 0.02 – 0.254 g/cm^3 (Rezanezhad et al., 2016). Due to land tilling and movement of people in the cropland, cultivated site was expected to have a relatively higher BD. Organic matter improves soil properties which include bulk density as OM holds soil particles together therefore changing the soil's shape and size (Bauer, 1974). Thus, as OM increases, BD decreases (Chaudhari et al., 2013)

The very high soil moisture content of peatland soils could be attributed to its high OM content as it increases peat's water holding capacity (Bauer, 1974). Results revealed that grassland contained the highest water content (85.67%), followed by forestland (76.29%) and cultivated land (75.39%).

Average water table drawdown in each vegetation cover type was discovered to be lowest in forestland which was 97.5 cm from the soil surface. This might be due to the fact that drainage canals were established near this land use at a distance of approximately 1.5 meters. Relatively higher water tables were found in grassland (26 cm) and cultivated land (26.5 cm).

Peat is very high in carbon content which is approximately 50%-58% of the dry organic matter (Joosten, Hans; Clarke, 2002). To do a generic conversion of soil organic carbon from organic matter (OM), OM is simply divided by the conversion factor of 1.72 (Pribyl, 2010). Since Soil Organic Carbon (SOC) is an estimate of Soil Organic Matter (SOM), SOC was observed to be highest also at the grassland site.

SOC stock expressed in tonnes of carbon per hectare can be computed by multiplying the soil organic carbon (%) by the mass of soil in a given volume, bulk density and soil layer depth (Dincă, Dincă, Vasile, Spârchez, & Holonec, 2015).

SOC Stock=(SOC)x(Bulk density x Depth x Area)

Typically, forestlands and grasslands are net C sinks while cultivated lands could be minor sources (Schrumpf et al., 2011). This generalized statement concurred with the results of this experiment which indicated that SOC stocks were higher in both forestland and grassland with 63.41 tC/ha and 53.56 tC/ha, respectively while a relatively low C stock was observed in the cultivated land with only 39.89 tC/ha (Table 2).

Table 2. Soil Organic Carbon Stocks across sites

LAND USE/ SITE	SOC STOCKS (tC/ha)
Forestland	63.41
Cultivated land	39.89
Grassland	53.56
AVERAGE	**52.29**

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It should be noted that these calculations took into consideration the layer depth of 0-30 cm or the top soil as this layer contains the most organic matter and carbon (Angst et al., 2018).

3.2 GHG flux assessments

Figure 2 shows the various land uses inside the peatland ecosystem while Table 3 describes the estimated GHG fluxes across sites during wet season.

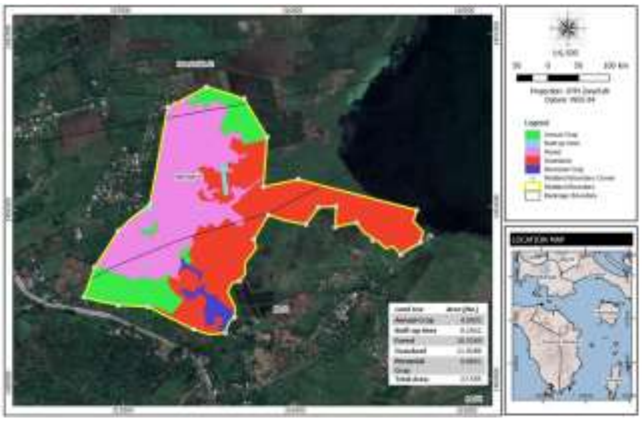

Figure 2. Land use map of Bambanin Peatland

Table 3. Greenhouse Gas Fluxes across sites during wet season

LAND COVER/SITE	CO_2	CH_4	N_2O
Forestland (10.55 has)			
Average flux, umol m^{-2} min^{-1}	656.70	0.008	0.076
Average flux, Mg $ha^{-1}y^{-1}$	151.91	0.001	0.017
Total Fluxes, Mg $ha^{-1}y^{-1}$	1602.60	0.007	0.184
Cultivated (4.00 has)			
Average flux, umol m^{-2} min^{-1}	374.85	0.156	0.031
Average flux, Mg $ha^{-1}y^{-1}$	86.71	0.013	0.007
Total Fluxes, Mg $ha^{-1}y^{-1}$	346.84	0.053	0.030
Grassland (11.93 has)			
Average flux, umol m^{-2} min^{-1}	215.70	6.870	0.014
Average flux, Mg $ha^{-1}y^{-1}$	49.89	0.580	0.003
Total Fluxes, Mg $ha^{-1}y^{-1}$	595.25	6.924	0.039
Total Fluxes of the whole peatland, Mg $ha^{-1}y^{-1}$	**2544.69**	**6.98**	**0.25**

Table 4 reflects the comparison of means expressed as mean ± standard error for greenhouse gas emissions across different sites in Bambanin peatland.

Table 4. Comparison of means for greenhouse gas fluxes across sites

LAND USE	CO_2	CH_4	N_2O
Forestland	656.7 ± 187.97	0.01± 0.08	0.08 ± 0.01
Cultivated	374.85 ± 21.85	0.16 ± 0.08	0.03 ± 0.01
Grassland	215.7 ± 35.64	6.87 ± 4.99	0.01 ± 0.00

Greenhouse gases (GHGs) are the main causes of rising temperature of the Earth's atmosphere otherwise known as global warming. Such phenomenon is induced by anthropogenic activities. The three generally recognized GHGs are carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O) characterized by their long atmospheric lives and their relatively high thermal absorption capacities (Barbera, Vymazal, & Maucieri, 2019; Courtois et al., 2018).

In most peatland ecosystems, drainage became a very common activity so that peat soils can be utilized for agriculture but this action causes greenhouse gas emission particularly CO_2 emission (Couwenberg, 2009). Such is also the case in Bambanin peatland where drainage canals measuring between 0.5 to 1.5 meters deep could be seen practically everywhere. The deepest canals where observed to be established near the forested area. Table 2 shows the greenhouse gas fluxes across study sites and will be discussed individually in the following pages. It is worth mentioning that the values obtained in this study were gross instead of net GHG emissions.

Carbon Dioxide (CO_2)

Environmental factors such as soil temperature, soil moisture, and available carbon triggers soil CO_2 fluxes (Barbera et al., 2019). Due to its high emission amount of more than 60% and being a

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strong absorber of infrared radiation, CO_2 became the most important greenhouse gas and has long been used as a refrence gas despite its very low global warming potential (GWP) of 1. This is considered to be the lowest among all of the GHGs earlier mentioned (Dellasala, Goldstein, Cloy, & Smith, 2018).

In the flux measurement conducted, CO_2 emission was observed to be highest in the forestland. As mentioned in the earlier discussions, sampling points in the forested area were near drainage canals which might have caused the high CO_2 flux, an average flux of 151.91 Mg $ha^{-1}yr^{-1}$. Drainage increases emissions of CO_2 but lowers emissions of CH_4 (Strack, 2008). It can be recalled that this land use had the lowest organic matter (OM) content (11.25%) and water table drawdown (97.5 cm below the soil surface). Please refer to Figure 3.

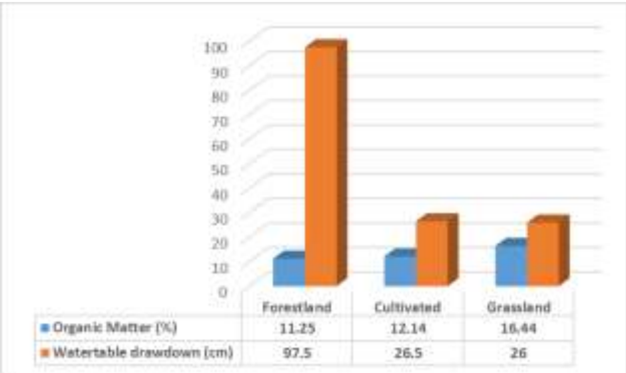

Figure 3. Organic matter content and water table drawdown across sites in Bambanin peatland

Unstable organic matter may disrupt global C cycle contributing to climate change (Lopes-Mazzetto, Schellekens, Vidal-Torrado, & Buurman, 2018). Water table drawdown, on the other hand, hastens peat oxidation and decomposition leading to increased carbon emissions (Dohong et al., 2017). When water table is low, mineralization of the oxic portion of peat soils occurs releasing CO_2 to the atmosphere (Leng et al., 2018). In addition to this, the decomposition of tropical peat soil both in their drained and natural environments mainly releases CO_2 (IPCC, 2014). Average CO_2 fluxes of cultivated land and grassland were 86.71 Mg $ha^{-1}yr^{-1}$ and 49.89 Mg $ha^{-1}yr^{-1}$, respectively (Figure 4).

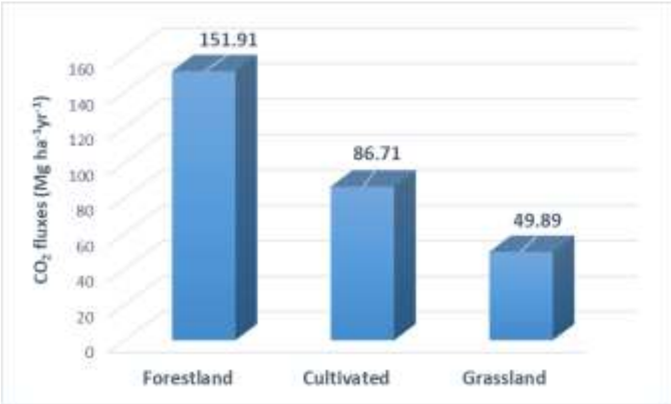

Figure 4. Gross CO_2 fluxes across sites

Tillage, as already mentioned previously, speeds up organic matter decomposition leading to increased CO_2 emission. The grassland where the sampling was conducted, on the other hand, was an undisturbed part of the peatland, hence, emission is expected to be very low. The total CO_2 emission of the whole peatland area was 2,544.69 Mg $ha^{-1}yr^{-1}$, the highest emission among the three greenhouse gases under study during wet season that made this peatland evidently a huge CO_2 source. Its mean fluxes ranged between 215.7 to 656.7 umol m^{-2} min^{-1} as seen in Table 3.

Methane (CH_4)

The emission of CH_4 in peatland ecosystem is mainly driven by the activities of methanogenic archaea under anoxic conditions through the process of diffusion, ebullition and transport facilitated by plants (Couwenberg & Fritz, 2012). High methane emission is particularly evident in a rice production system that demands a relatively huge volume of water. Previous research on the effect of water table level on the greenhouse gas emissions from a peatland discovered that high emissions of CH_4 is closely associated with high water table (Dinsmore et al., 2009).

Drained peatland barely releases CH_4 as water table is one of the main controls of methane production in natural or pristine peatlands (Joosten, Hans; Clarke, 2002). The contribution of CH_4 is comparatively smaller than CO_2 emissions in drained peatlands (Couwenberg, 2009). This explains the relatively low average amount of CH_4 released in the atmosphere from the three study sites (Forestland, 0.001 Mg $ha^{-1}yr^{-1}$; Cultivated land, 0.013 Mg $ha^{-1}yr^{-1}$; Grassland, 0.580 Mg $ha^{-1}yr^{-1}$) in Bambanin peatland during the time of collection (Figure 5).

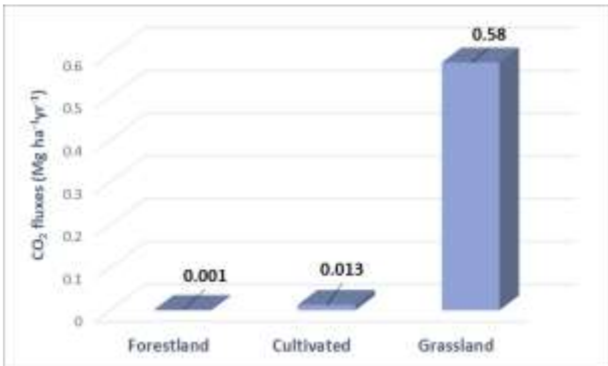

Figure 5. Gross CH_4 fluxes across sites

Total CH_4 emission was 6.98 Mg $ha^{-1}yr^{-1}$ which was comparatively low with CO_2 emission as reference. Its mean fluxes ranged from 0.01 to 6.87 umol m^{-2} min^{-1}.

Nitrous Oxide (N_2O)

The N_2O emissions are generally influenced by some environmental variables that include soil moisture, soil pH, temperature, water table level, vegetation, agricultural practices and availability of organic carbon (Courtois et al., 2018). Agriculture actually represents 66% of the total N_2O emissions sources (Jalota et al., 2018). The emissions are enhanced by the application of fertilizers for improved yields. In Bambanin peatland, only 18.82% of the farmers interviewed apply fertilizers with frequency of 1-4 times per cropping season.

N_2O emissions from peatlands also decrease with acidic soil environment and low nitrogen content (Joosten, Hans; Clarke, 2002). Negligible emissions of N_2O are generally observed in nutrient-poor soils like peatlands (Couwenberg, 2009). In fact, a study conducted over a year by Inubushi, Furukawa, Hadi, Purnomo, & Tsuruta (2003) on the seasonal variations in the emissions of CO_2, CH_4 and N_2O in South Kalimantan, Indonesia acquired a negative value for N_2O emissions across sites under study. The results of this experiment followed almost the same trend which reflected the very low, almost negligible average emissions of N_2O across land uses during the wet season (Forestland, 0.017 Mg $ha^{-1}yr^{-1}$; Cultivated land, 0.007 Mg $ha^{-1}yr^{-1}$; Grassland, 0.003 Mg $ha^{-1}yr^{-1}$). Please refer to Figure 6. Of the three GHGs studied from Bambanin peatland, N_2O displayed the smallest production with a total of 0.25 Mg $ha^{-1}yr^{-1}$ with mean fluxes that ranged from 0.01 to 0.08 umol m^{-2} min^{-1}.

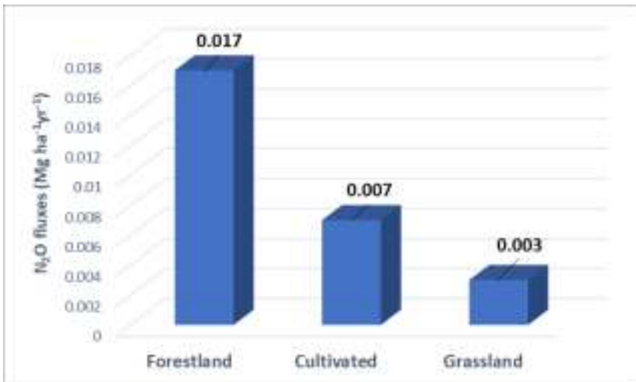

Figure 6. Gross N_2O fluxes across sites

4. Conclusions and recommendations

Generally, the peat soil was acidic and nutrient poor that resulted to very low quality of produce and yields. Considering that Bambanin peatland is relatively young, organic matter (OM) content and soil organic carbon (SOC) were comparatively low. However, OM content of Bambanin peat soil that was between 11-16% was much higher than the mineral soils. Such high OM content explains the high water holding capacity of the peatland.

Very low water table levels in Bambanin peatland enhanced peat decomposition and consequently the release of CO_2 in the atmosphere. Sites close to drainage canals, particularly forested and cultivated areas, had the highest water table drawdown.

The computed SOC stocks that ranged between 39.89-63.41 tC/ha fell within the range of carbon that peat soils can store which is accordingly 30-700 t/ha (Agus, Hairiah, & Mulyani, 2011). This is a clear evidence that Bambanin peatland is a carbon sink that helps mitigate the effects of climate change.

The huge amount of CO_2 released by the Bambanin peatland proved that this ecosystem could also be a C source. Such emission is enhanced by anthropogenic activities such as farming, drainage and deforestation. These human interventions are major threats to peatland degradation. On the contrary, almost negligible amounts of CH_4 and N_2O were emitted by the peatland.

Results of this study could be used in formulating mitigation policies to address issues on the unmanaged utilization of the peatland ecosystem including peatland hydrology. These could also serve as baseline information for more intensive and in-depth researches like the GHG inventory and carbon stock assessment in all the confirmed peatlands in the country and also to contribute in the regional and global GHG inventories. Through these efforts, widespread degradation of peatlands could be avoided while continuous provision of ecosystem services will be ensured.

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7. Appendices

Appendix 1: Soil physico-chemical parameters at varying soil depth

Soil Fractions/ Depth (cm)	pH	%N	P (ppm)	K (me/100g)	%OM	SOC %	% SAND	% CLAY	% SILT
Forestland									
F-0-30	5.3	0.7908	1.4817	0.3750	15.8171	9.1960	88	0	12
F-30-75	4.6	0.7587	1.0127	0.3847	15.1714	8.8206	68	22	10
F-75-100	5.2	0.6052	1.0127	0.3507	12.1046	7.0376	66	26	8
F-100-150	5.5	0.2723	1.0594	0.3701	5.4466	3.1666	64	20	16
F-150-200	5.3	0.3843	1.9554	0.3798	7.6862	4.4687	54	28	18
AVERAGE	**4.6-5.5**	**0.56**	**1.30**	**0.37**	**11.25**	**6.54**	**68.00**	**19.20**	**12.80**
Cultivated land									
C-0-30	5.3	0.2541	1.2466	0.3362	5.0834	2.9555	26	58	16
C-30-75	4.7	0.5568	1.0127	0.3070	11.1361	6.4745	78	12	10
C-75-100	4.5	0.7465	1.9554	0.3362	14.9293	8.6798	80	12	8
C-100-150	4.5	0.6254	1.2466	0.3022	12.5081	7.2722	54	36	10
C-150-200	4.3	0.8534	1.0127	0.3070	17.0673	9.9228	96	0	4
AVERAGE	**4.3-5.3**	**0.61**	**1.29**	**0.32**	**12.14**	**7.06**	**66.80**	**23.60**	**9.60**
Grassland									
G-0-30	4.8	0.698	1.1997	0.3507	13.9608	8.1167	88	4	8
G-30-75	4.7	1.1015	5.4138	0.3119	22.0308	12.8086	82	8	10
G-75-100	5.0	1.0592	1.576	0.3653	21.1833	12.3159	90	2	8
G-100-150	5.0	0.3954	1.3875	0.3507	7.9078	4.5976	74	16	10
G-150-200	5.4	0.8554	1.0594	0.4235	17.1084	9.9467	76	14	10
AVERAGE	**4.7-5.4**	**0.82**	**2.13**	**0.36**	**16.44**	**9.56**	**82.00**	**8.80**	**9.20**