Soil Organic Carbon Content in Different Wetlands of Chi River Basin

Utain Chanlabut

A Thesis Submitted in Partial Fulfillment of Requirements for
degree of Doctor of Philosophy in Biology
March 2019

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ของ

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The examining committee has unanimously approved this Thesis, submitted by Mr. Utain Chanlabut , as a partial fulfillment of the requirements for the Doctor of Philosophy Biology at Mahasarakham University

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ABSTRACT

Wetlands are considered as the most productive ecosystem on earth. However, the capacity to store soil carbon has a high degree of variability from place to place, and it depends on many factors. Wetland ecosystems have been studied in many regions, but little is known about the storage of soil organic carbon especially freshwater wetlands in Thailand. Thus, the aims of this study were; (1) to quantify soil organic carbon in wetlands of the Chi River Basin and (2) to study factors influencing the accumulation of organic carbon in wetlands soils.

Nine freshwater wetlands were selected as representatives of wetlands in the Chi River Basin. Three of hydrologic zones was set up in order to collect soil samples in each wetland: (1) intermittently flooded zone, (2) saturated zone, and (3) permanently flooded zone. Five sampling stations were randomly set up on each of hydrologic zone. Soil samples were collected at a depth of 0 – 50 cm and were divided into 5 cm increments to observe changes of soil organic carbon concentration in soil profiles. Core method was also used for collecting soil sample in order to determine soil bulk density. Coverage of vegetation was also investigated to assess dominated vegetation. The soil samples were dried at the room temperature and analyzed for soil organic carbon and soil parameters (soil pH and soil texture). Two-ways ANOVA was used for testing the effect of both hydrologic schemes and soil depths on the accumulation of soil organic carbon. One-way ANOVA was used to determine differences of soil organic carbon pools among soil depth, among hydrologic schemes, and among wetland sites.

The results revealed that wetlands in this study were dominated by herbaceous vegetation. Thus, these wetlands can be identified into freshwater marsh with mineral soils. Soil organic carbon concentration decreased with depth in soil profiles from all wetland sites, suggesting that wetland soils had sustained accumulation of soil organic carbon. Also, soil organic carbon was significantly higher in the upper soil depth. The soil organic carbon concentration (0 – 50 cm) differed significantly among hydrologic zones. Both intermittently flooded zone and saturated zone had higher soil organic carbon concentration while the permanently flooded zone was generally low in all wetlands. At a depth of 0 – 50 cm, Nonghan

Kumphawapi had the highest soil organic concentration (36.69 g C kg^{-1}). Nong Waeng Non-hunting Area had the lowest one (4.92 g C kg^{-1}). The average of total soil organic carbon pool of all wetlands was 230±34.84 Mg C ha^{-1}, ranging from 123 to 429 Mg C ha^{-1}. Nonghan Kumphapi had the largest carbon pool while Bueng Kluea had the lowest one. Among hydrologic schemes of wetlands, the soil organic carbon pools were 77.38±11.63 Mg C ha^{-1} (38 – 142 Mg C ha^{-1}) in the intermittently flooded zone, 85.14±13.53 Mg C ha^{-1} (38 – 152 Mg C ha^{-1}) in the saturated zone, and 68.33±18.32 Mg C ha^{-1} (31 – 213 Mg C ha^{-1}) in the permanently flooded zone. More than 50% of soil organic carbon pools of each wetland were generally stored in the upper 25 cm of the soil profiles.

Keyword : Carbon stock, Hydrologic schemes, Chi River Basin, Northeast Thailand

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CHAPTER 1
INTRODUCTION

1.1 Backgrounds

Climate change causes many severe effects including outbreaks of diseases, drought, flood, the variability of precipitation. Consequently, many of organisms are under risk of extinction, and human well-being is impacted (Thomas et al. 2004). Climate change is caused by greenhouse gases such as carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O). These are emitted and accumulated in the atmosphere by 391 part per million (ppm) 1,083 part per billion (ppb) and 324 ppb, respectively. Emission of greenhouse gases is primarily because of anthropologic activities including fossil fuel burning, land use change, and agriculture. The most important of greenhouse gases is CO_2, which has been being released in a higher amount than did others greenhouse gases. Further, emission of CO_2 has contributed to increase of mean global temperature by 0.5 – 1.3 °C during 1990 – 2010 (IPCC 2013), resulting in rising of sea level as well as melting of ice sheet and glacier. This problem has been concerned by many countries, which try to stabilize the concentration of atmospheric CO_2 by reducing the emission of greenhouses gases as well as increasing sinks of carbon. The effective method of reducing atmospheric CO_2 is carbon sequestration, the process which transfers carbon dioxide into global carbon reservoirs includes; ocean, fossil fuel, biota, and soil reservoirs by using biological and chemical process (Lal 2008). Currently, there are a wide and deep interest in soil carbon because of their potential to decrease GHGs through soil carbon sequestration (McBratney et al. 2014).

Soils play an important role as sinks and sources of carbon (Lal 2010). Globally, it is estimated that soils store an amount of 2,500 PgC (1 Pg = 10^{15} g) at a depth of 1 meter (Lal 2008). Thailand also has been reported on soil organic carbon stock at the depth of 1 meter by 6.21 PgC or 0.046% of global soil organic carbon (Moncharoen and Vearasilp 2001). Wetlands have the potential to accumulate organic carbon in soils. As a result, wetland soil plays an important role in climate regulation. Globally, it is estimated that wetland soils store 20 – 30% of global soil organic carbon (455 – 700 PgC) despite the fact that wetlands cover only 6 – 8% of the global surface (Villa and Mitsch 2015; Mitsch and Gosselink 2015). Carbon is accumulated in wetland soils by an input of organic matter (productivity of plant biomass and sedimentation) and lost by an output of organic matter (decomposition and soil erosion/leaching). Remains of organic materials are accumulated under an anaerobic condition as organic matters, which were combined with mineral fractions to form soil organic carbon (Mitsch and Gosselink 2015).

In Thailand, wetlands cover an area of 36,616 km^2 or approximately 7.5% of the country area, which comprise a wide range of wetland types such as riverine, lacustrine, palustrine and coastal ecosystems. Many wetlands associated with the riverine systems that people utilized as land for agriculture or water resources. In addition, wetlands are used as aquaculture, sand mining as well as the implementation of development project such as the construction of dams for irrigation and electricity generation (Office of Environmental Policy and Planning 2000). The Chi River Basin is one three major tributaries of Mekong River, creating a watershed area of 49,480 km^2. There are many important wetlands in this basin. Some are very important in the national and international level such as Nonghan Kumphawapi, Bueng Lahan, Kaeng Lawa, Nong Sam Muen, Sop Mun-Chi, etc. These wetlands provide many ecosystem services to local communities. For instance, more than 80% of the total incomes of dwellers around Sop Mun-Chi are derived from resources in the wetland. In Nong Sam Muen, 50 – 80% of income in the community is also derived from using wetland resources (Office of Environmental Policy and Planning 2000). Wetlands not only are essential for human livelihood but may also play a key function as a potential sink of soil carbon (Millennium Ecosystem Assessment 2005). In Thailand, the function of the wetlands as sinks of soil organic carbon is less understood and rarely studied. In order to highlight the function and services of wetland in the Chi River Basin as national carbon sinks, the study of soil organic carbon on wetland soils is urgently needed. Amount of soil organic carbon in wetlands will be a key for understanding ecosystem service of wetlands as climate regulator, and essential for deciding to appropriately use of wetlands and sustainable development, which lead to offset greenhouse gases emissions.

1.2 Objectives of the study

1.2.1. To quantify soil organic carbon content in different wetlands of the Chi River Basin

1.2.2. To study the relationship between soils organic carbon and the factors that influence the accumulation of organic carbon in wetland soils

1.3 Scope of the study

The study was carried out in 9 different wetlands located in the Chi River Basin. All studied sites are the wetlands that have been designated as the nationally important wetlands and nationally important wetlands based on the Ramsar criteria. The research was mainly focused on the accumulation of organic carbon in wetland soils at a depth of 0 – 50 centimeters. Soil parameters including soil reaction (Soil pH), soil textures, and soil color were also studied. Also, the coverage of vegetation was investigated in each sampling stations.

1.4 Expected results and application

1.4.1 Soil organic carbon content in both nationally important and internationally important wetlands of the Chi River Basin

1.4.2 Different potential of soil organic carbon storage of both nationally important and internationally important wetlands of the Chi River Basin

1.5 Hypothesis of the study

1.5.1 Soil organic carbon content would differ among three hydrologic schemes of each wetland.

1.5.2 Soil organic carbon would differ among soil depths of the wetland soil profile.

1.5.3 Potential of soil organic carbon accumulation would differ among wetland sites.

1.6 Conceptual framework of the study

The research has been carried out for 36 months (January 2016 – December 2018). The conceptual framework of this research was shown in Figure 1.

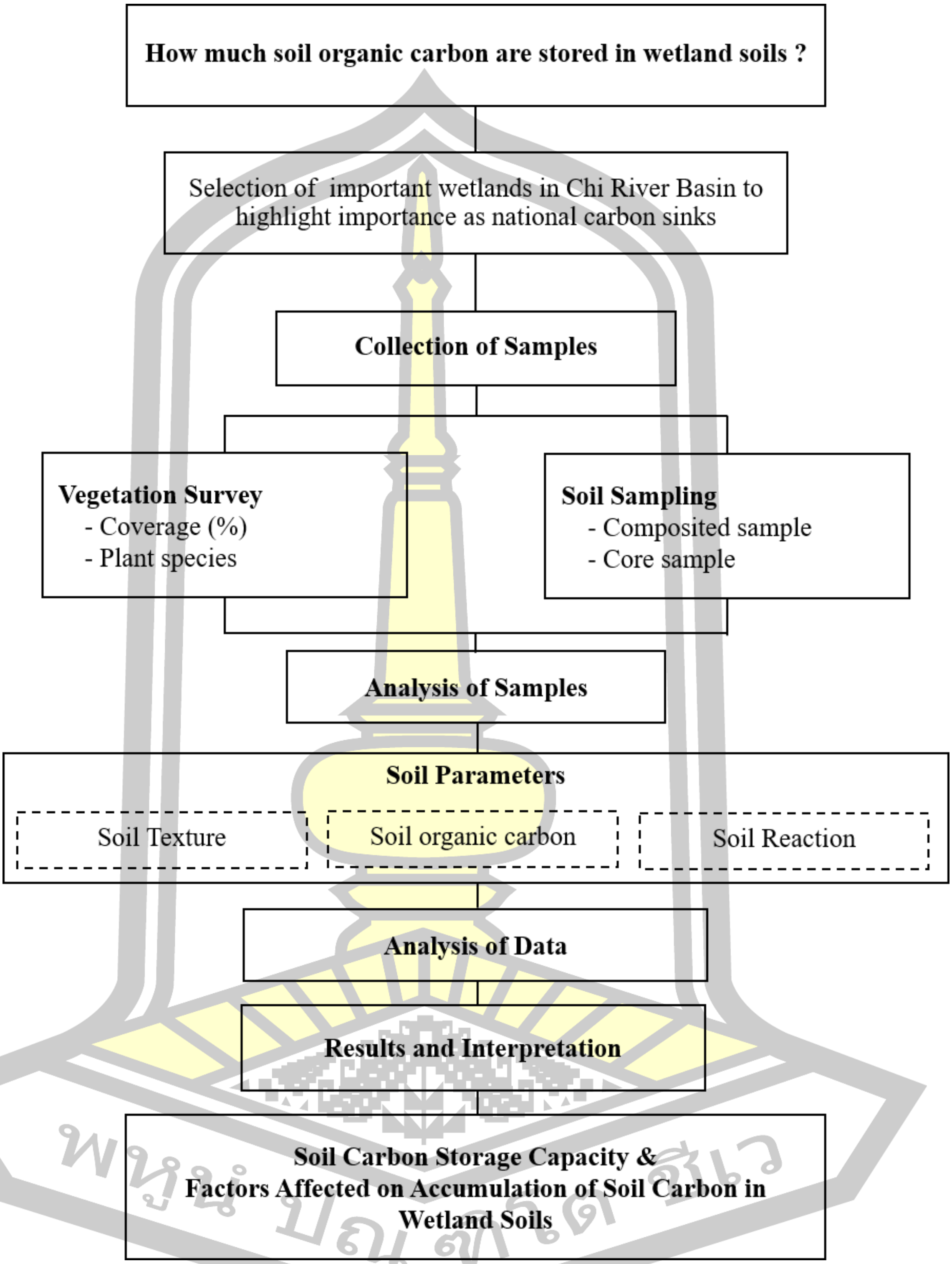


Figure 1 The conceptual framework of the study

CHAPTER 2
REVIEW LITERATURES

The study of soil organic carbon in wetland ecosystems of the Chi River Basin related to several theories and literature, comprising the topics as follows.

2.1 Definition of wetlands
2.2 Characteristics of wetlands
2.3 Global carbon reservoirs
2.4 Roles of wetlands in the global carbon cycle
2.5 Wetland ecosystems in Thailand

2.1 Definitions of wetlands

Definition of wetlands is important for: (1) wetland scientists and (2) wetland managers and regulators (Mitsch and Gosselink 2015). For the scientific purpose, scientists use the definition to classify, inventory, and research. For management purpose, the definition related to laws and regulations. The delineations are designed to prevent and control management and modifications of wetlands. Usage of definitions depends on different purposes. This study related to ecological studies on wetland ecosystems. Thus, the definitions of wetlands are mostly reviewed in scientific definitions. However, the definitions in management purpose are also reviewed in this section. Wetlands have been defined by both governments and international treaty. The definitions are as follows.

The Ramsar convention has defined wetlands that “wetlands are areas of marshes, peatlands or water, whether natural or artificial, permanent or temporary, with water that is static or flowing, fresh, brackish or salt including areas of marine water, the depth of which at low tide does not exceed six meters. They may incorporate riparian and coastal zones adjacent to the wetlands, and islands or bodies of marine water deeper than six meters at low tide lying within the wetlands” (Finlayson and Moser 1991).

The U.S. Fish and Wildlife Service defined wetland as “the lands transitional between terrestrial and aquatic systems where the water table is usually at or near the surface or the land is covered by shallow water. For purposes of this classification wetlands must have one or more of the following three characteristics: (1) at least periodically, the land supports predominantly hydrophytes; (2) the substrate is predominantly undrained hydric soil; and (3) the substrate is non–soil and is saturated with water or covered by shallow water at some time during the growing season of each year” (Cowardin et al. 1979).

In Canada, wetlands have been defined as “land that has the water table at, near, or above the land surface or which is saturated for a long enough period to promote wetland or aquatic processes as indicated by hydric soils, hydrophytic vegetation and various kind of biological activity which are adapted to the wet environments. Wetland may also include waterlogged soils where in some cases the production of plant material exceeds the rate of decomposition. Wetlands also have shallow open water with less than 2 meters and periodically inundated areas only if waterlogged conditions dominated throughout the development of ecosystem” (Zoltai and Vitt 1995).

The U.S National Academy of Science Definition defined wetlands as “A wetland is an ecosystem that depends on constant or recurrent, shallow inundation or saturation at or near the surface of the substrate. The minimum essential characteristics of wetland are recurrent, sustained inundation or saturation at or near the surface” (National Research Council 1995).

For legal purpose, to protect wetland from modification and loss, the U.S. Army Corps of Engineers Definition have defined wetlands as “those areas that are inundated or saturated by surface or groundwater at frequency and duration enough to support, and that under normal circumstances do support, a prevalence of vegetation typically adapted for life in saturated soil conditions. Wetlands generally include swamps, marshes, bogs, and similar areas” (Brinson 1993).

Therefore, there are various definitions of wetlands. All have been developed and used for many purposes. For ecological studies and inventories, the U.S. Fish and Wildlife Service definition should be applied for defining of wetland in this study. The Ramsar definition is still widely used for international even the meaning is quite wide for defining wetland boundaries. For management and regulation purpose, the U.S. Army Corps of Engineers' definition is probably the most appropriated (Mitsch and Gosselink 2015).

Although definitions of wetlands have been developed, the common terms are also used to denote types of wetlands in much of research (Bernal and Mitsch 2012; Bernal and Mitsch 2013a; Marín-Muñiz et al. 2014; Doughty et al. 2016; Carnell et al. 2018). Globally, there are many terms that used for representing wetlands (Table 1). These words can denote to common characteristics in wetlands such as soils, plants communities, and hydrology, and three components are always used for classified wetland into many types. As a result, some terms can be used to roughly identified wetlands. However, some terms are so confusing and misunderstanding because they have specific meaning to some people in specific regions. For example, marshes are well known as wetland dominated by herbaceous plants. Swamps are wetlands that dominated by woody plant either shrub or trees. Peatlands is a common term that is used to name a peat-accumulating system. Bogs and fens are also used as common terms of peatland. However, the terms do not convey the same meaning within the international scientific community. In Russia, peatlands and bogs are denoted to the forested wetland instead of swamp because they are common features of the landscape in the country. In North America, the word swamp is referred to a wetland dominated by the woody plants. In Africa, a swamp is a wetland referred to as a marsh in America. Swamps in New Zealand and the United Kingdom are referred to wetland dominated by cattail (*Typha*) despite this plant is herbaceous species. The wetlands that dominated by *Phragmites* (common reed) in Europe are also called reed swamps instead of called marshes (Mitsch and Gosselink 2015).

There are confusions in the usage of terminology because different region and continents use terms for representing similar wetland type. To prevent confusing in use, the users should be considered two points before using the common terms to classify wetlands (Mitsch and Gosselink 2015). First, the physical and biotic characteristics should be described and accompanied by terms. Second, the common terms are still used in much scientific research. Before using, they should be used with caution and described additional data for international audiences.

Table 1 The common terms used for denoted wetland types in the word

Terms	**Meaning of terms**
Billabong	The term represents a riparian wetland in Australia that is periodically flooded by the adjacent stream or river.
Bog	A peat-accumulating wetland that has no significant inflows or outflows and supports acidophilic mosses, particularly *Sphagnum*.
Bottomland	Lowland along streams and rivers, usually on alluvial floodplains, that is periodically flooded. When forested, it is called a bottomland hardwood forest in the southeastern and eastern United States.
Carr	The term used in Europe for forested wetlands characterized by alders (*Alnus*) and willows (*Salix*).
Cumbungi swamp	Marsh dominated by Cattail (*Typha*) in Australia.
Dambo	A seasonally waterlogged and grass-covered linear depression in the headwater zone of rivers with no marked stream channel or woodland vegetation. The term is from the Chichewa (Central Africa) dialect meaning “meadow grazing.”
Delta	A wetland-river-upland complex located where a river forms distributary as it merges with the sea; there are also examples of inland deltas, such as the Peace-Athabasca Delta in Canada and the Okavango Delta in Botswana.
Fen	A peat-accumulating wetland that receives some drainage from surrounding mineral soil and usually supports marsh like vegetation.
Lagoon	The term frequently used in Europe to denote a deep-water enclosed or partially opened aquatic system, especially in coastal delta regions.
Mangal	Same as mangrove.

Table 1 (continued)

Terms	**Meaning of terms**
Mangrove	A subtropical and tropical coastal ecosystem dominated by halophytic trees, shrubs, and other plants growing in brackish to saline tidal waters. The word mangrove also refers to the dozens of tree and shrub species that dominate mangrove wetlands.
Marsh	A frequently or continually inundated wetland characterized by emergent herbaceous vegetation adapted to saturated soil conditions. In European terminology, a marsh has a mineral soil substrate and does not accumulate peat. See also tidal freshwater marsh and salt marsh
Mire	Synonymous with any peat-accumulating wetland (European definition); from the Norse word myrr. The Danish and Swedish word for peatland is now mose.
Muskeg	Large expanse of peatlands or bogs; particularly used in Canada and Alaska.
Moor	Synonymous with peatland (European definition). A highmoor is a raised bog; a lowmoor is a peatland in a basin or depression that is not elevated above its perimeter. The primitive sense of the Old Norse root is "dead" or barren land.
Oxbow	Abandoned river channel, often developing into a swamp or marsh.
Pakihi	Peatland in southwestern New Zealand dominated by sedges, rushes, ferns, and scattered shrubs. Most pakihi form on terraces or plains of glacial or fluvial outwash origin and are acid and exceedingly infertile.
Peatland	A generic term of any wetland that accumulates partially decayed plant matter (peat).

Table 1 (continued)

Terms	**Meaning of terms**
Playa	An arid– to semiarid–region wetland that has distinct wet and dry seasons. The term is used for shallow depressional recharge wetlands occurring in the Great Plains region of North America "that are formed through a combination of wind, wave, and dissolution processes"
Pocosin	Peat–accumulating, no riparian freshwater wetland, generally dominated by evergreen shrubs and trees and found on the southeastern coastal plain of the United States. The term comes from the Algonquin for "swamp on a hill."
Pokelogan	Northeastern U.S. marshy or stagnant water that has branched off from a stream or lake.
Pothole	Shallow marsh-like pond, particularly as found in the Dakotas and central Canadian provinces, the so-called prairie pothole region.
Raupo swamp	Cattail (*Typha*) marsh in New Zealand.
Reedmace swamp	Cattail (*Typha*) marsh in the United Kingdom.
Reed swamp	Marsh dominated by Phragmites (common reed); term used particularly in Europe.
Riparian ecosystem	The ecosystem with a high–water table because of proximity to an aquatic ecosystem, usually a stream or river. Also called bottomland hardwood forest, floodplain forest, bosque, riparian buffer, and streamside vegetation strip.
Saltmarsh	A halophytic grassland on alluvial sediments bordering saline water bodies where water level fluctuates either tidally or nontidal.
Sedge meadow	Very shallow wetland dominated by several species of sedges (e.g. *Carex*, *Scirpus*, and *Cyperus*).

Table 1 (continued)

Terms	**Meaning of terms**
Shrub-Scrub Swamp	A freshwater wetland transitional between a forested swamp and a wet meadow or marsh, dominated by shrubs, with trees having less than 20 percent cover and less than 10 m height.
Slough	An elongated swamp or shallow lake system, often adjacent to a river or stream. A slowly flowing shallow swamp or marsh in the southeastern United States (e.g., cypress slough). From the Old English word sloh, meaning a watercourse running in a hollow.
Strand	Same as a slough; a slow-flowing riverine/wetland system, often forested, found especially in south Florida, where gradients are low.
Swamp	Wetland dominated by trees or shrubs (U.S. definition). In Europe, forested fens and wetlands dominated by reed grass (*Phragmites*) are also called swamps (see reed swamp).
Tidal freshwater marsh	Marsh along rivers and estuaries close enough to the coastline to experience significant tides by non-saline water. Vegetation is often same as nontidal freshwater marshes.
Turlough	Areas seasonally flooded by karst groundwater with sufficient frequency and duration to produce wetland characteristics. They generally flood in winter and are dry in summer and fill and empty through underground passages. A term is specific for these types of wetlands found mostly in western Ireland.
Vernal pool	Shallow intermittently flooded wet meadow, generally typical of Mediterranean climate with a dry season for most of the summer and fall. The term is now used to indicate wetlands temporarily flooded in the spring throughout the United States.

Table 1 (continued)

Terms	**Meaning of terms**
Vleis	Seasonal wetland same as a dambo; term used in southern Africa.
Wad (pl. Wadden)	Unvegetated tidal flat originally referring to the northern Netherlands and northwestern German coastline. Now used throughout the world for coastal areas.
Wet meadow	Grassland with waterlogged soil near the surface but without standing water for most of the year.
Wet prairie	Like a marsh, but with water levels usually intermediate between a marsh and a wet meadow.

Source: Mitsch and Gosselink (2015)

2.2 Characteristics of wetlands

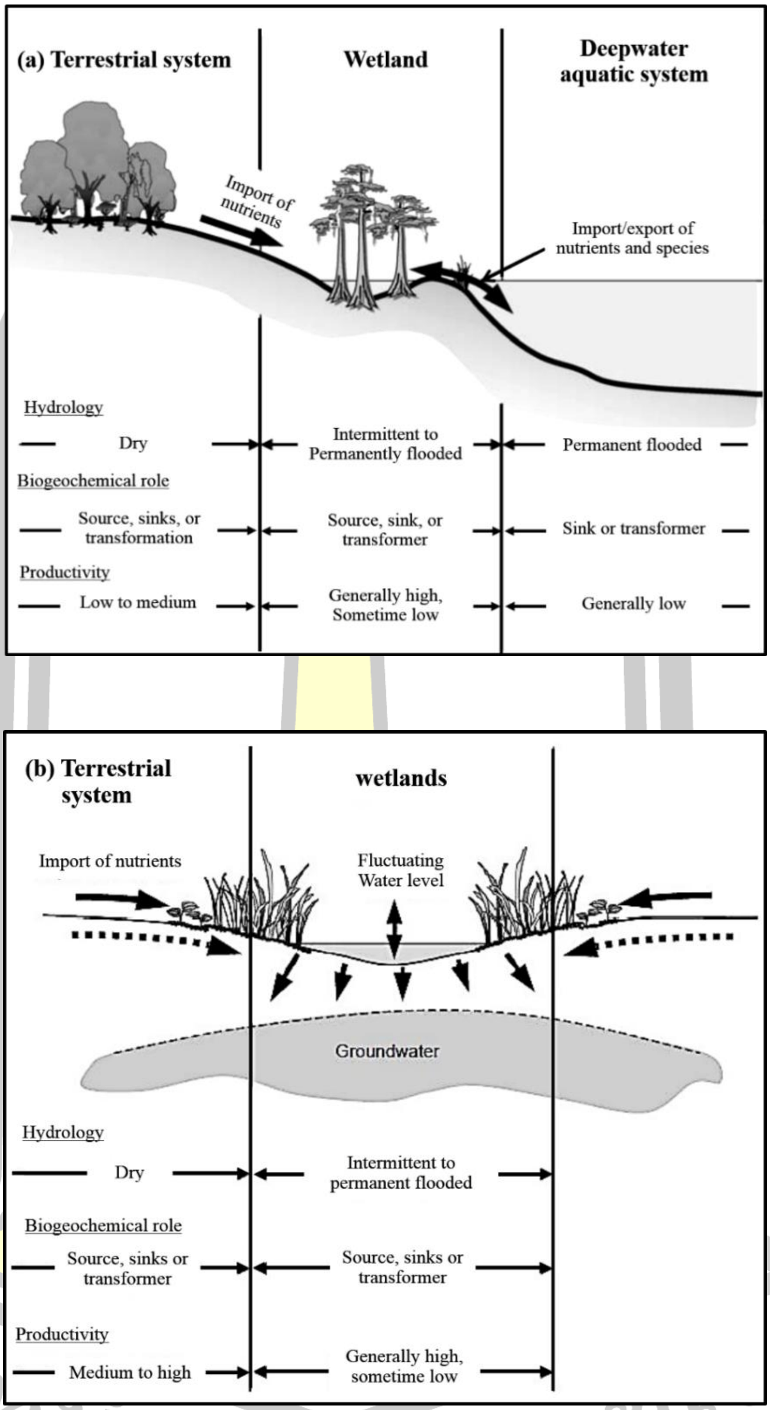
Wetlands have many distinguishing characteristics depending on their types. However, all wetland types have the unique characteristics in common (Mitsch and Gosselink 2015): (i) all have shallow or saturated soil, which is called "*hydric soils*" (ii) all accumulate organic plant material that decomposes slowly and (ii) all support variety of plants and animals adapted to the saturated conditions. To identifies any areas to be wetland ecosystems, the area should, therefore, comprise three main components

(1) Presence of water either at the surface or the root zone during at least some part of seasons.

(2) Soils in the wetland are saturated by water. They are unique and different from the adjacent uplands.

(3) Organisms that lived in wetlands adapted to the wet conditions especially vegetations (hydrophytes), which have the specific physiology to thrive in flooding conditions

According to the main component of the wetland ecosystem, they are usually present in the ecotone between terrestrial and deepwater aquatic systems (Figure 2a). On the other hand, wetlands also exist in isolated situations where the groundwater near the land surface (Figure 2b). Wetlands combine the properties of both terrestrial and aquatic ecosystems. So, they can be sinks, sources of transformers nutrient from both ecosystems. This characteristic provides wetlands being the most productive ecosystems on Earth. The interaction of three components (hydrology, soil, and vegetation) made up special characteristics and communities of wetlands, which can be used to classified wetland types. The U.S. fish and wildlife service classify wetlands to 5 categories; marine, estuarine, riverine, lacustrine, and palustrine (Cowardin et al. 1979). The U.S. Army Corps of Engineers classify wetlands into 4 categories (Brinson 1993); depressional, riverine, fringe, and extensive peatlands, by using the classification system based on the hydrogeomorphic setting. Three sources of water feed on wetland systems; precipitation, groundwater discharge, and surface inflow, with three hydrodynamics; vertical fluctuation, unidirectional flow, and bidirectional flow.



Applied from: Mitsch and Gosselink (2015)

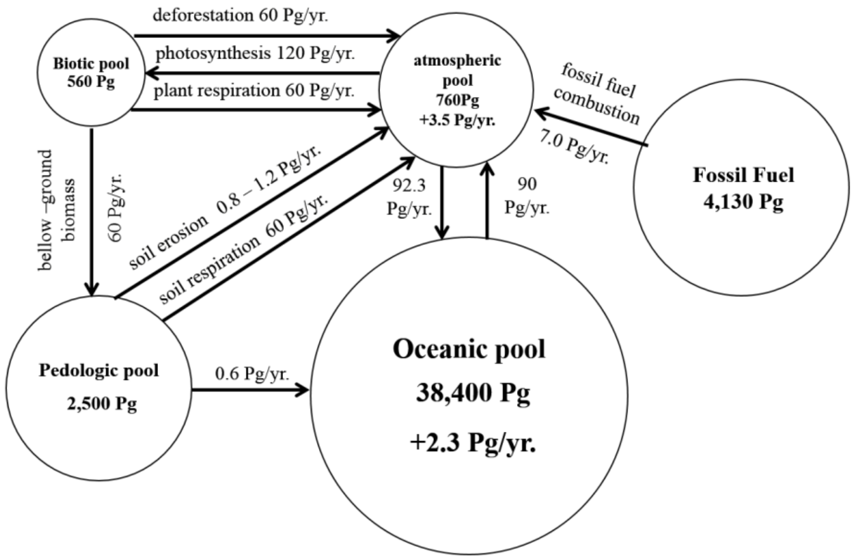
Figure 2 Wetlands usually occur in the areas of (a) an ecotone between terrestrial systems and permanently flooded deepwater aquatic systems such as rivers, lakes, estuaries, or oceans or (b) isolated wetlands with little outflow and no adjacent deepwater system.

Hydrology plays an important role for functions and services of wetland ecosystems. The wet conditions create physiochemical conditions that differed from the adjacent ecosystems such as terrestrial and aquatic ecosystems. The hydrologic conditions such as water depth, flow pattern, duration, and frequency of flooding, which are the results of hydrologic input and output, influencing the biochemistry of wetland soils. It also results in the growth of organisms in particular macrophytes (Mitsch and Gosselink 2015). Generally, plant biomass production or net primary productivity associated with hydrologic pulsing. The edge of wetlands, where subjected to intermittently flooding, always have higher production of biomass than do permanently flooding in the same wetlands (Odum 1969; Odum et al. 1995).

Wetland soils are unique because it is subjected to flooding during parts of a season. There are two majors of soils in wetland ecosystems: organic soils and mineral soils (Vepraskas and Craft 2016). The organic soils are formed by the accumulation of plant debris, that are decomposed slowly under anaerobic conditions which are the results of excessive wet conditions in wetland ecosystems. Organic soils are porous, light in weight, and black. Generally, the bulk density of organic soils ranges from 0.02 to 0.35 g cm^{-3} (Vepraskas and Craft 2016). Organic soils always have higher organic carbon content than do mineral soils. Percentage of organic carbon in organic soils is more than 12 – 20% while mineral soils are less than that (Mitsch and Gosselink 2015). Mineral soils consist of the different amount of soil particles (sand, silt, and clay). As a result, mineral soils are weightier than organic soils. Soil bulk density of mineral soils falls within the range of 1.0 – 2.0 g cm^{-3} (Mitsch and Gosselink 2015).

2.3 Global carbon reservoirs

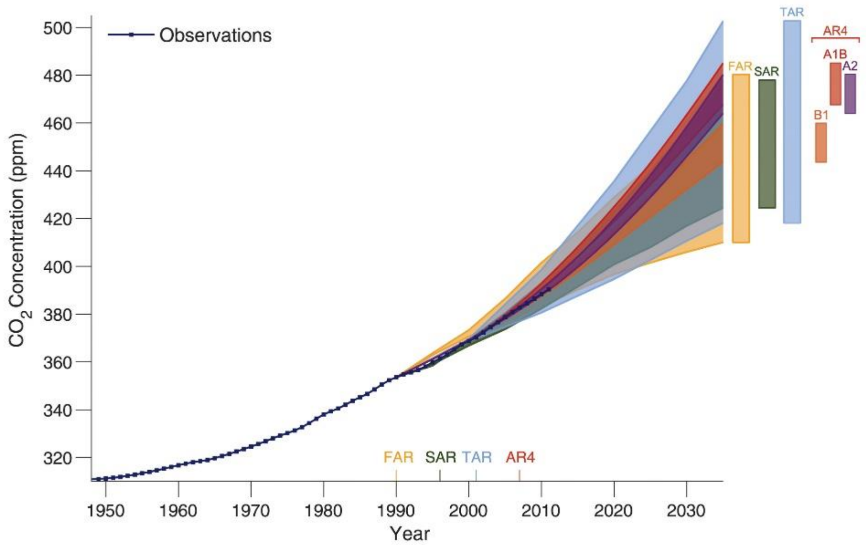
There are five principal carbon reservoirs on the earth (Figure 3). Carbon is transformed and exchanged among the reservoirs. CO_2 is an important form of carbon that causes global warming, and it is enormously emitted to the atmosphere via fossil fuel burning and cement production. It is estimated that CO_2 is stored in the atmosphere approximately 555 PgC, with an increased rate of 2 ppm yr^{-1} (IPCC 2013). Further, the rate of increase will rise continuously in the future (Figure 4). However, CO_2 is also interchanged among other reservoirs including oceanic, fossil fuel, biotic and soil reservoirs by the natural and anthropogenic process. The ocean is the largest carbon reservoirs (38,000 PgC), whereas the fossil fuel reservoirs are the second, containing about 4,000 Pg C. Soil reservoirs contain 2,500 PgC, which is about three times of atmospheric reservoir and five times of biotic reservoir. Soil reservoir comprises two component of soil carbon; soil organic carbon (SOC) and soil inorganic carbon (SIC). At depth of 1 meter, soil contains about 1,500 PgC and 950 PgC of SOC and SIC, respectively (Eswaran et al. 1993; Batjes 2014).



Applied from: Lal (2008)

Figure 3 Five principal global carbon reservoirs and dynamics

Anthropogenic activities such as fossil fuels burning, deforestation, and land use change have been resulting in the balance of exchange CO_2 between the global carbon reservoirs, leading to excess CO_2 in the atmosphere (Lal 2008). This increase the global mean surface temperature, a well-known indicator of climate change, increased by approximately 0.85 ˚C during 1880 – 2012. The rising temperature causes global warmer continuously, which have led to declining of snow cover and melting of the glacier. Global sea level has risen as well as oceans heat content has increased. During the 20th century, it is estimated that a sea level has increased by approximately 1.7 millimeters per year. The major cause of climate change is an increase of greenhouse gases in the atmosphere including CO_2, CH_4, and N_2O. The main emission activities include fossil fuel burning, cement production, land use change, and agriculture. It is estimated that CO_2 increased by 40% from 278 ppm in 1750 to 390.5 ppm in 2011. While CH_4 increased by 150% from 772 ppb to 1803 ppb and N_2O by 20% from 271 to 324.2 ppb in 2011 (IPCC 2013).



Source: IPCC (2013)

Figure 4 Trend of carbon dioxide concentration in the atmosphere since 1950

Generally, a substantial atmospheric CO_2 can be sequestered through photosynthesis then accumulated in plant tissues. Forest ecosystem plays an important role as carbon stock and regulating amount of CO_2 in the atmosphere. The forest ecosystem is account for 1,240 Pg C (Dixon and Wisniewski 1995). The global carbon was stored in the three principle forest biomes; boreal, temperate and tropical forest. In forest ecosystems, organic carbon is mainly stored in aboveground and belowground biomass and soils. The amount of carbon stock between vegetation and soils are different among ecosystems (Table 2). Especially in the forest ecosystem, the amount of carbon in both soils and vegetation depends on the region of forest ecosystems. As non-annex 1 parties in Kyoto protocol, Thailand has a commitment to report the status of sinks and sources of carbon from many sectors of the nation. As a result, many ecosystems in Thailand have been evaluated soil carbon stock, especially in the protected areas. Most of the study on soil carbon stock is carried out in forest ecosystems, plantations, and agricultural ecosystems. Soil carbon stocks differed among ecosystems (Table 3). Forest ecosystems have the ability in absorbing CO_2 by the trees and store a large amount of carbon stock in soils. Although forest has the potential to accumulate carbon in their systems, wetland ecosystems are also a highly productive ecosystem. However, wetlands in Thailand are rarely studied on soil carbon stocks. Therefore, understanding carbon storage in wetland soils could highlight the role of wetlands in national carbon sinks, which will make wetlands as important as the forest ecosystems are.

Table 2 Carbon stocks at 1 meter's depth in different biomes

Biome	**Area ($\times 10^6$ ha)**	**C density (Mg ha^{-1})**		**C stock (Pg)**	
		Vegetation	**Soil**	**Vegetation**	**Soil**
Tundra	927	9	105	8	97
Boreal/Taiga	1,372	64	343	88	471
Temperate	1,038	57	96	59	100
Tropical	1,755	121	123	212	216
Wetlands	280	20	723	6	202
Total	**5,672**	**(mean) 54**	**(mean) 189**	**373**	**1,086**

Source: Lal (2005)

Table 3 Soil carbon stock in different ecosystems in Thailand

Ecosystems	**Depth (cm)**	**Carbon Stock (Mg C ha^{-1})**	**Sources**
Dry evergreen forest	0 – 50	118	Lichaikul et al. (2006)
Hill evergreen + mixed deciduous forest	0 – 100	197	Pibumrung et al. (2008)
Mixed deciduous forest	0 – 100	157	Tangsinmankong et al. (2007)
Take Plantation	0 – 100	71	Tangsinmankong et al. (2007)
Reforestation‡	0 – 100	147	Pibumrung et al. (2008)
Plantation of Acacia	0 – 50	66	Lichaikul et al. (2006)
Corn field	0 – 50	57	Lichaikul et al. (2006)
Agriculture†	0 – 100	95	Pibumrung et al. (2008)
Agroforestry system	0 – 100	4	Podong and Permpool (2017)
Re-afforestation area covered by:			Nualngam (2002)
Acacia mangium	0 – 30	53	
Acacia auriculaformis	0 – 30	37	
Neyraudia reynaudiana	0 – 30	49	
Imperata cylindrica	0 – 30	45	
Xylia xylocarpus var. kerrii	0 – 30	43	
Dalbergia cochichinensis	0 – 30	42	
Eucalyptus camadulensis	0 – 30	38	
Pterocarpus macrocarpus	0 – 30	38	

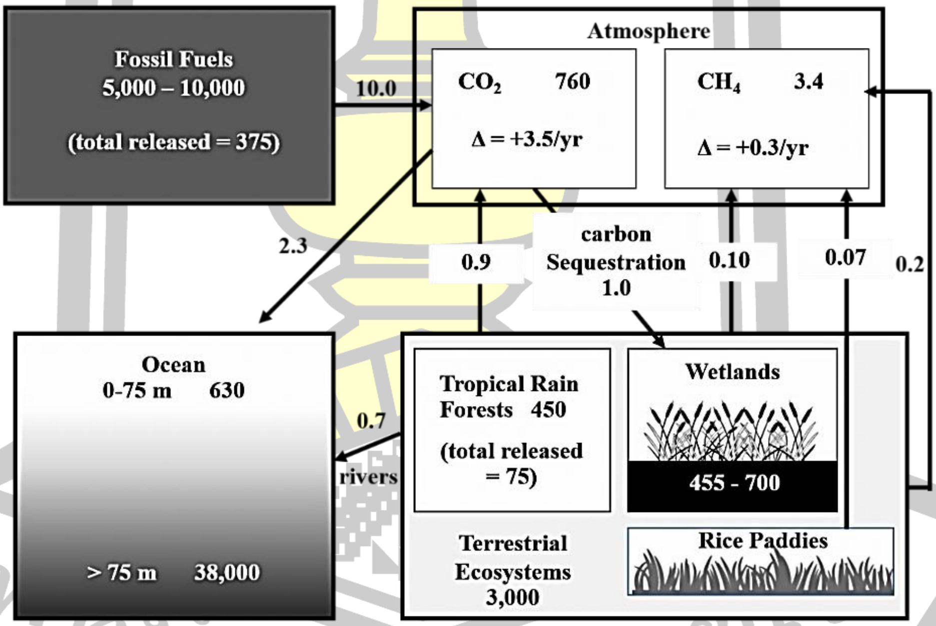
Remarks

† comprise: Fallow land, Paddy field, cornfied, and Orchard (*L. chinensis* Sonn. spp.)

‡ comprise: *G. aborea* Roxb., *T. grandis* Linn., *P. marcrocarpus* Kurz., *A. xylocapa* (Kurz) Craib., and *A. catechu* (L.f.) Wild.

2.4 Roles of wetlands in the global carbon cycle

Wetlands provide a variety of ecosystem services and functions, which support human well-being such as fish, water supply, water purification, climate regulation (Millennium Ecosystem Assessment 2005). In the aspect of global climate, wetlands play an important role in climate regulator. Wetlands can be sources and sinks of greenhouse gases simultaneously (Figure 5). A function of regulating climate in wetlands is made up by hydrology, one of the unique characteristics of these systems. Generally, wetland ecosystems have a presence of standing water in the wetland (Mitsch and Gosselink 2015). As a result, oxygen cannot be diffused into soils profile in flooding conditions. This creates an anaerobic condition in wetland soils, and provides a slow decomposition of organic matter, as well as emission of CH_4 from anaerobic respiration.



Applied from: Mitsch and Gosselink (2015)

Figure 5 The role of wetland in the global carbon budget. Unit of soil carbon storage expresses as PgC while carbon fluxes are PgC yr^{-1}.

As a global carbon sink, wetlands are among the most productive ecosystem on Earth (Table 4). The production of biomass in wetlands is higher than the other ecosystems. As a result, wetlands stores about 20 – 30% (455 – 700 PgC) of global soil carbon pool despite covering 6 – 8% of the global land area (Mitsch and Gosselink 2015). The accumulation of soil organic carbon in wetlands depends on input (organic matter produced in wetland/from other systems) and output (decomposition/ erosion). Organic matters can be input to wetland soils in 2 ways (Qualls and Richardson 2003): (1) autochthonous input; organic matter is produced in wetland ecosystems and (2) allochthonous input; wetland receives organic matters from sediment from other systems. For autochthonous input, organic matters accumulated from the production of biomass in macrophytes. By sequestering CO_2 via photosynthesis, carbon is accumulated in plant tissue as aboveground and belowground biomass. When plants were dead, litters and debris are accumulated in wetland soils. For allochthonous, depositional sediments can be accumulated in wetland system during flooding seasons. However, the wetland can be sources of carbon whereby soil organic carbon in wetland soils are lost by erosion and leaching, and decomposition. CH_4 are emitted from wetlands through anaerobic respiration by microorganisms. As a result, CH_4 is released into the atmosphere by 20 – 25% of annual global CH_4 emission (Whalen 2005). Another, soil organic matters that deposited in the surface of wetland soils can be leached and exported from wetlands in flooding season (Walalite et al. 2018), especially in wetlands where connected with main river and floodplain area (Mulholland and Kuenzler 1979).

Table 4 Net primary productivity of different types of ecosystem

Ecosystems	**Net primary productivity (gC m^{-2} yr^{-1})**
Desert	80
Boreal forest	430
Tropical forest	620 – 800
Temperate forest	65
Wetlands	1,300
Cultivated land	760
Tundra	130

Source: Reddy and DeLaune (2008)

Although wetlands are rich-carbon ecosystems, rates of carbon sequestration varied widely among wetland types (Table 5). This suggested that capacity in sequestering carbon of wetlands is uncertain, and there are spatial differences on the accumulation of soil carbon. As shown in Table 5, the rate of accumulation varied among wetlands even the same climate region. The spatial difference could be a result of many factors such as climate regions, time of inundation, species composition, type of organic input system (Bernal and Mitsch 2008; Bernal and Mitsch 2012; Bernal and Mitsch 2013b; Carnell et al. 2018). Plant community influence the accumulation of soil organic carbon in wetland ecosystems whereby the production of plant biomass (primary productivity), which are different among plant species and wetland types (Table 6). Mangrove showed higher primary production than do other wetlands. In freshwater marshes, emergent plants produced the highest biomass while submerged plants had the lowest biomass production. In salt marshes, wetland, where *Juncus* are dominant, had higher primary production than do wetlands dominated by *Spartina*. Wetlands dominated by herbaceous always have low organic carbon in soils than do swamps where dominated by woody plants. Reddy and DeLaune (2008) revealed that herbaceous plants are poor in lignin. As a result, the herbaceous are more decomposable than the woody plants. Disturbance of wetlands can also influence the amount of organic carbon in wetlands. Land uses, and water regulation surrounded wetlands could result in both autochthonous and allochthonous input into wetland systems (Carnell et al. 2018).

Many wetlands have been studied on soil organic carbon. The organic carbon in wetland generally has spatial differences, and storage of soil carbon depends on many factors. Temperate wetlands (17.6 kg C m^{-2}) had the highest carbon pools than did tropical ones (9.7 kg C m^{-2}), and soil organic carbon also differed within tropical climate, whereby the humid tropic wetland (96.5 g C kg^{-1}) had higher soil carbon concentration than do the tropical dry ones (34.8 g C kg^{-1}) (Bernal and Mitsch 2008; Bernal and Mitsch 2013a). Ricker and Lockaby (2015) revealed that soil carbon stocks differed among distinct floodplain landscapes. At a depth of 100 cm, soil carbon stocks were 533 Mg C ha^{-1} in organic wetlands, 193 Mg C ha^{-1} in mineral wetlands, and 108 – 109 Mg C ha^{-1} in flat and levees. Soil organic content was also different between climate regions. In Australia, soil carbon stock varied widely among wetland types. The soil carbon stocks ranged from 64 to 290 Mg C ha^{-1}, with a mean of 186±176 Mg C ha^{-1} (Carnell et al. 2018). Alpine wetlands (290 Mg C ha^{-1}) contain the highest soil carbon stock, whereas open freshwater wetlands (64 Mg C ha^{-1}) and saline wetlands (110 Mg C ha^{-1}) contain the lowest soil carbon stocks (Carnell et al. 2018). Soil organic carbon pool differed among three wetland types-isolated forested, riverine flow-through, and slow-flow slough. The isolated forested wetland had the highest carbon pool (10.8 kg C m^{-2}), while the riverine flow-through wetlands (7.9 kg C m^{-2}) and the slow-flow slough (8.0 kg C m^{-2}) had the lowest soil carbon pools (Bernal and Mitsch 2008). Organic carbon in wetland soils differed among hydrogeomorphic types and plant communities. Depressional wetlands (144.0 g C kg^{-1}) had higher soil organic carbon than do riverine one (46.6 g C kg^{-1}). Within the depressional wetland, marsh showed higher soil organic carbon (156.7 g C kg^{-1}) than do shrub and forested communities (132.7 and 141.0 g C kg^{-1}, respectively). Within the riverine wetlands, floating bed communities had the highest soil organic carbon (81.3 g C kg^{-1}), while marsh and mudflat communities had the lowest soil organic carbon (22.3 and 34.9 g C kg^{-1}, respectively) (Bernal and Mitsch 2012).

Although many wetlands have been studied in many regions to highlight the importance of wetlands as global carbon sinks, the organic carbon in wetland soils in Thailand has not been well documented. Moreover, many wetlands in Thailand are considered as free resources of water and lands. Many of them have been therefore used as agricultural land, which could diminish the ecological functions such as ability in storing soil carbon. Therefore, there is gap knowledge of soil organic carbon in wetlands. The study on soil organic carbon in this ecosystem is urgently needed in Thailand so that these wetlands will be used and managed wisely to reduce the loss of function, especially carbon sinks. This can offset the emission of greenhouse gases into the atmosphere, on both local scale and national scale.

Table 5 Carbon sequestration in wetlands

Wetland Types	Rate of Sequestration ($g\ m^{-2}\ yr^{-1}$)	References
Northern Peatlands		
Boreal peatlands	29 ± 13	Turunen et al. (2002)
Boreal peatlands	15 – 26	Turunen et al. (2002)
Temperate peatlands	10 – 46	Turunen et al. (2002)
Russian tundra peatlands	−8 – 38	Heikkinen et al. (2002)
Coastal Wetlands		
Mangroves, North America	180	Chmura et al. (2003)
Salt marshes, North America	220	Chmura et al. (2003)
Tidal freshwater wetlands, North America	140 ± 20	Craft (2007), Craft et al. (2008)
Brackish marshes, North America	240 ± 30	Craft (2007), Craft et al. (2008)
Salt marshes, North America	190 ± 40	Craft (2007), Craft et al. (2008)
Mangrove swamps, S.E. Asia	90 – 230	Suratman (2008)
Coastal wetlands, S.E. Australia, Undisturbed sites	105 – 137	Howe et al. (2009)
Coastal wetlands, S.E. Australia, Disturbed sites	64 – 89	Howe et al. (2009)
Mangroves (global)	160 ± 40	Breithaupt et al. (2012)
Mangroves (global)	226 ± 39	Mcleod et al. (2011)

Table 5 (continued)

Wetland Types	Rate of Sequestration ($g\ m^{-2}\ yr^{-1}$)	References
Tropical/Subtropical Freshwater Wetlands		
Tropical/subtropical wetlands	194 ± 56	Mitsch et al. (2013)
Florida Everglades, general	86–387	Reddy et al. (1993)
Tropical freshwater wetland, Indonesia	56	Page et al. (2004)
Tropical freshwater wetland, Indonesia	94	Page et al. (2004)
Cyperus wetland in Uganda	480	Saunders et al. (2007)

Source: Mitsch and Gosselink (2015)

Table 6 Net primary productivity of different types of wetlands

Wetland types	**Net primary productivity (g m^{-2} yr^{-1})**
Saltmarsh	
Spartina	65 – 1,850
Juncus	2,938 – 4,043
Bogs and fens	
Sphagnum	30 – 1,660
Other mosses	10 – 507
Species excluding mosses	177 – 1,027
Marshes (freshwater)	
Submerged macrophytes	1 – 1,000
Floating macrophytes	10 – 2,067
Emergent macrophytes	155 – 6,180
Mangroves	1,000 – 4,599
Riparian	334 – 804
Southern deepwater swamps	130 – 770

After: Reddy and DeLaune (2008)

2.5 Wetland ecosystems in Thailand

Thailand, a tropical country situated in the Indo–Chinese peninsular, lie between latitude 97º 30´ – 105º 45´ East and longitude 5 º 45´ – 20 º 30´ North. The distance from north to the south border is approximately 1,500 kilometers, and the distance from east to west is approximately 500 kilometers. Thailand has an area of 513,155 square kilometers. All area comprises 5 geographical regions including Northern, Northeastern, Central and Western, Eastern and Southern region. These have very diverse geographical characteristics such as mountainous, highland, plateau, lowland and floodplain. Wetlands in Thailand are mostly associated with river and floodplains. The total area of wetland covers an area of 36,616.16 square kilometers, or 7.5% of the country area, which includes a very wide range of wetland types as shown in Table 7 (Office of Environmental Policy and Planning 2000). Most of the wetlands in Thailand are influenced by the river system and lakes (Table 7).

Table 7 Types and number of wetlands in Thailand

No.	Systems	Number of sites
1.	canals, steam, and rivers	25,008
2.	lakes	14,128
3.	marshes and inundated plains	1,993
4.	seas, coastal areas and estuaries	1,256
5.	not be classified	268
	Total	**42,653**

Source: Office of Environmental Policy and Planning (2000)

Office of Environmental Policy and Planning (2000) reported that there are many types of wetland distributes across areas of the country (Table 9). The southern part of the country has several wetland sites while which of a northeastern part is less than other parts of the country. In the Northern region, complex mountainous topography creates many important rivers (Ping, Wang, Yom, and Nan). The areas along these rivers are floodplains, where comprise many important wetlands such as Kwan Pa Yao in Pa Yao province, Bueng Boraphet in Nakhon Sawan province and Bueng Seefai in Pichit province. In Northeastern Region, the region is comprised of Khorat Plateau and Sakon Nakhon basin lower plain. The Mun and Chi River Basin are very important in this region, which covers 75% of total region area and locates on the Khorat Plateau. The Chi River is the longest river in Northeastern region, comprising many tributaries including the Prom River, the Choen River, and the Lam Pao. Water from these is discharged into the Chi River. The Mun River also comprise many tributaries such as the Lam Takhong, the Lam Sey Bai, the Lam Sey Bok, the Lamplaimat, the Lam Dome Yai and the Lam Dome Noi, which discharge into the Mun River. The Chi River also discharges into the Mun River in Ubon Ratchathani province and bring about the large flood in the confluence area. Beside Khorat Plateau, Sakon Nakhon basin lower plain is also important, situated between the Mekong River and the Phupan Moutain Range. The lower plain comprises many important rivers such as Songkhram, Loei and Hueng Rivers, which discharge into the Mekong River. In Central and Eastern, river plain is mostly found, which created several marshes, ponds, and lakes in these regions. The central part of the region is the great plain formed by alluvial sediments. The river delta occurs in the southern part of the region. Wetlands in the central and eastern regions are associated with riverine plain. The northern part of the central region, north, and west to east is surrounded by the mountain range, which gradually slopes toward to the south. Marshes spread across these areas. The sedimentation forms many large river deltas. Mudflats are found in coastal areas, where rivers discharge into the Gulf of Thailand. Narrow waterways passing through continuous mountain range are found in the western part, whereas riverine plain lies in a northeastern to the southeastern direction in the eastern region. The eastern region comprises many bays and beautiful beaches, coastlines, coastal plains, and mountain. In the southern region, there are various wetlands distributed on the region, which includes small rivers, peat swamp forests, mangrove forests, mud flats, sandy beaches, seagrass beds, coral reefs, and islands. These wetlands are important for waterfowl and migratory birds especially Thale Noi, the wetland situated at the north of Songkhla Lake. The Andaman Sea, the western coastline of this region, has a large area of mangroves which are important for the breeding of many marine species. In addition, Phru To Daeng peat swamp forest is also the best example of a peat swamp system in Thailand.

Wetlands in Thailand have been explored and recorded across the country in order to designate wetlands as important wetlands, especially, importance as habitats of waterfowl. Based on the Ramsar criterion, wetlands have been designated and listed into an inventory of wetlands of international and national importance in Thailand (Office of Environmental Policy and Planning 2000). The criterion for designation of wetlands emphasizes ecosystem services and functions as habitats for vegetation and organisms, especially rare species and endemic species. The wetlands in the inventory play an important role in the local population in local livelihood, culture, and regulation of local climates. According to the criteria, wetlands across Thailand have been designated into 3 ranks of important level—local importance, national importance, and international importance. Across the country, there are 61 sites designated as internationally important wetlands, 208 sites as nationally important wetlands, and 42,396 sites as locally important wetlands. In northeastern Thailand, many wetlands are designated as important wetlands; 12 sites of international importance, 45 sites of national importance, and 532 sites of local importance. These wetlands provide many benefits, which support human-wellbeing of people and organisms lived in this region.

The Chi River Basin is one of the three important basins of the Northeast Thailand (the Mekong, Mun and Chi Basin). There are 10 sites of important wetlands in the Chi River Basin—3 sites of international importance and 7 sites of national importance (Table 10). Office of Environmental Policy and Planning (2000) reported that these wetlands provide many ecosystem services, which support human well-being of people around wetland areas, especially economic and recreational services. For instance, 80% of the income in the community surrounded Sop Mun-Chi are derived from the wetland. In Nong Sam Muen, 50 – 80% of incomes in the community are also derived from the usage of resource in wetlands. Nonghan Kumphawapi is one of the destinations of tourist from over the world, which come to see The Red Lotus Lake, where dominated by *Nymphaea* spp. in the partial area of this wetland. Also, Bueng Kluea has been well known as a famous tourist's attraction of Selaphum district, the economy of the community is developed because the people from all around Roi Et province usually come to relax in this area, especially during the festival event. In addition, many important wetlands in the Chi River Basin are important for the production of fish and inland fisheries of local people. These wetlands not only deliver benefits for people livelihood but also provide habitats for living and forage of many species (Table 10). Also, wetlands support habitats for hydrophytes, which generally thrive in all wetlands. Although ecosystems service and functions of these wetlands have been recognized by people surrounded wetlands, the function as climate regulators especially national carbon sinks of these wetlands are unclear. Many studies on wetlands have suggested that wetlands play an important role as the global carbon sinks. Therefore, functions and ecosystem services as carbon sinks in wetlands in the Chi River Basin should be considered and appreciated because these wetlands are facing threatening from human activities. Recognizing these wetlands as national carbon sinks could provide people realizing about our changing climate, and lead to a wise use of wetland resource.

Table 8 The number of family and species vegetation in different hydrologic conditions of each freshwater wetlands in this study

Wetland sites	**Number of family**		**Number of genus**		**Number of species**	
	Intermittent	**Saturate**	**Intermittent**	**Saturate**	**Intermittent**	**Saturate**
Bueng Lahan	3	6	4	6	4	6
Nong Waeng Non-hunting Area	3	5	5	6	5	6
Nong Sam Muen	5	8	6	9	6	9
Kaeng Lawa	2	3	5	5	5	5
Huai Suea Ten	7	5	9	7	9	7
Nonghan Kumphawapi	5	9	6	10	6	10
Nong Pla Khun	5	7	8	7	8	7
Bueng Kluea	3	5	4	5	4	5
Sop Mun-Chi	6	7	6	7	6	7
All areas	**16**	**16**	**26**	**23**	**26**	**23**

Remarks: The number of species and families based on surveying in the sampling area.

Table 9 Types and number of wetlands in different regions of Thailand

Wetland Types	North		Northeast		Central and west		South	
	number	area (km^2)	number	area (km^2)	number	area (km^2)	number	area (km^2)
seas, coastal river and estuaries	–	–	–	–	387	671	869	19,513
river, streams, canals and flood-plains	5,461	1,117	8,053	1,092	8,380	164	3,114	393
ponds, lake and water reservoirs	4,573	1,678	6,168	836	2,228	2,353	1,159	3,643
marshes and inundated plain	539	26	368	50	750	142	336	491
not be classified yet	–	–	161	22	7	–	100	>1,000
Total	10,573	2,821	14,750	1,999	11,752	3,330	5,578	28,466

Source: Office of Environmental Policy and Planning (2000)

Table 10 Lists of the important wetlands in the Chi River Basin

Wetland sites	Locality	Areas (km^2)	Number of species	
			birds	fish
International importance				
Phu Khioa wildlife sanctuary	Kaset Sombun District, Chaiyaphum	1,560.00	223	26
Nonghan Kumphawapi	Kumphawapi District, Udon Thani	45.00	74	39
Bueng Lahan	Chatturat District, Chaiyaphum	29.09	56	25
National importance				
Sop Mun Chi	Warin Chamrap District, Ubon Ratchathani	97.49	3	39
Kaeng Lawa	Ban Phai District, Khon Kaen	11.20	36	43
Huai Suea Ten	Nam Phong District, Khon Kaen	10.40	35	24
Nong Sam Muen	Phu Khioa District, Chaiyaphum	5.60	31	22
Nong Waeng Non – hunting Area	Khon Sawan District, Chaiyaphum	0.17	50	5
Nong Plakhun	Selaphum District, Roi Et	0.80	15	51
Bueng Kluea – Bo Kae	Selaphum District, Roi Et	0.75	28	54

Applied from: Office of Environmental Policy and Planning (2000)

CHAPTER 3

METHODOLOGY

The study on soil organic carbon in the different wetland of the Chi River Basin comprises many processes. Nine of the important wetlands on the basin were chosen to study. Soil samples and vegetation were collected from different hydrologic conditions in wetlands. Soil organic carbon and soil properties were analyzed in the laboratory. Soil carbon pools (soil carbon stocks) were calculated. Analysis of Variance (ANOVA) was used for comparing the soil organic carbon among wetlands, among soil depth, and among hydrologic schemes. The more details of each process are as follows.

3.1 Study sites

This study was carried out on the Chi River Basin, where the drainage area is approximately 49,129 km^2. The local climate has three major seasons: summer (March – June), rainy (July – October), and winter (November – February). The annual precipitation ranges from 900 to 1,700 mm, with an average of 1,174 mm. High rainfall is prevalent in the rainy season, on an average of 1041.1 mm (88.68% of annual rainfall) (Hydro and Agro Informatics Institute 2012). The Chi River comprises many sub-tributaries including the Nam Prom, Lam Nam Choen, Lam Nam Phong, Lam Pao, and Lam Nam Yang.

There are numerous freshwater wetlands and oxbow lakes distributed in the area of Chi River Basin. Some have been designated as the locally, nationally, and internationally important wetlands based on the Ramsar criteria, in the list of *an inventory of wetlands of international and national importance in Thailand,* (Office of Environmental Policy and Planning 2000). In this study, 9 wetlands on the Chi River Basin were chosen (Table 11) in order to study organic carbon in wetland soils. The wetlands in this study are under the floodplain area of either the Chi River or its tributaries. The location of these wetlands shown in Figure 6

Table 11 The selected wetland ecosystem on area of Chi River Basin

Wetland	Abbrv.	Area (km^2)	Elevations (meters)	Location	
				District	Province
International importance					
1. Nonghan Kumphawapi	HK	45.00	160 – 170	Kumphawaphi	Udon Thani
2. Bueng Lahan	LH	29.09	190	Chatturat	Chaiyaphum
National importance					
3. Nong Waeng Non-hunting Area	NW			Khon Sawan	Chaiyaphum
4. Nong Sam Muen	SM	5.60	205 – 220	Phu Khiao	Chaiyaphum
5. Kaeng Lawa	LW	11.20	160	Ban Phai	Khon Kaen
6. Huai Suea Ten	ST	10.40	160 – 170	Nam Phong	Khon Kaen
7. Nong Pla Khun	PK	0.80	130 – 135	Selaphum	Roi Et
8. Bueng Kluea	BK	0.75	130 – 135	Selaphum	Roi Et
9. Sop Mun – Chi	MC	97.49	100 – 110	Kanthararom Warin Chamrap, Mueang Ubon	Si Sa Ket Ubon Ratchathani

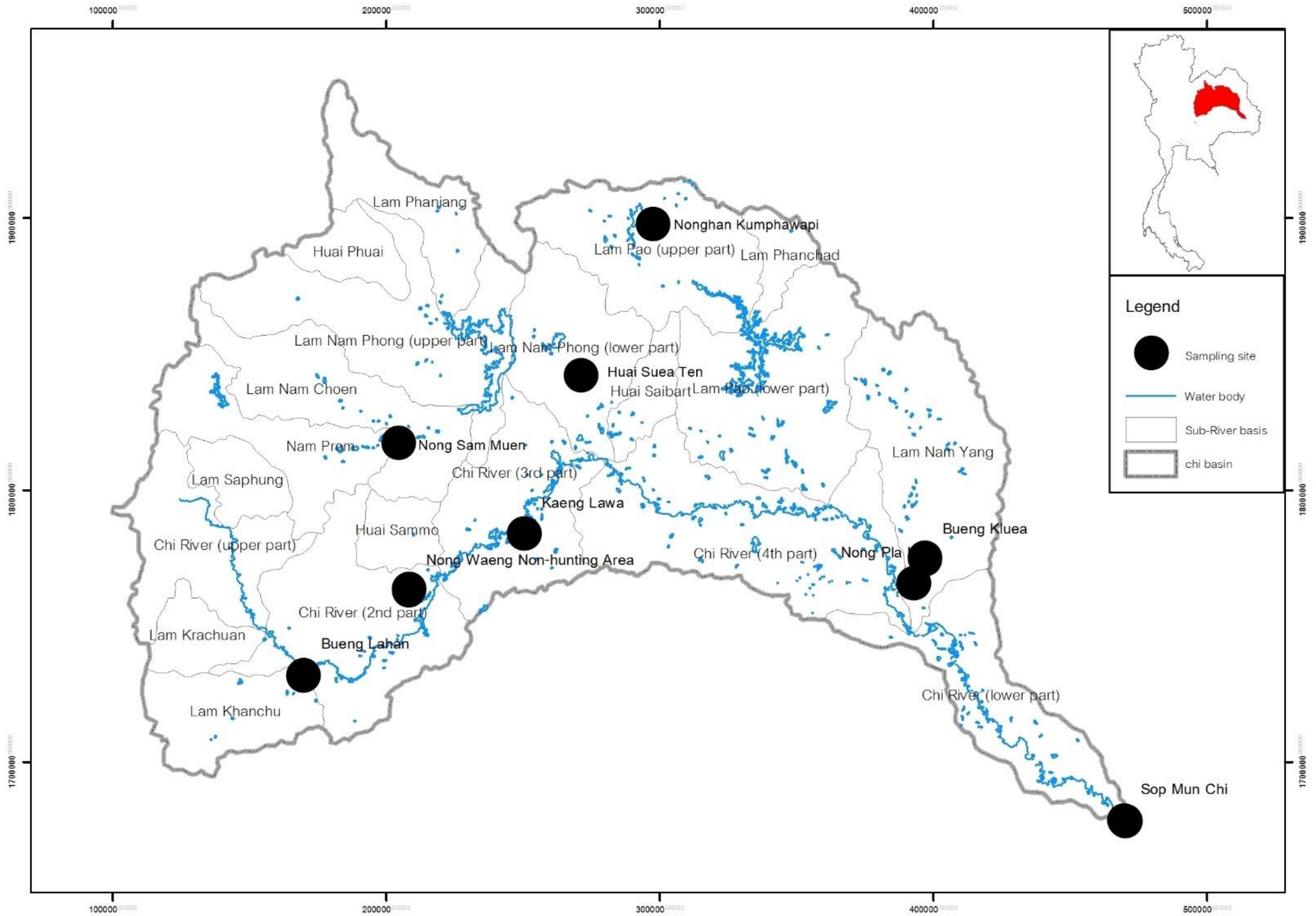


Figure 6 Locations of the studied wetlands in the Chi River Basin

3.2 Sample collection

Generally, wetland area has a gradient of inundation, ranging from shallower to deeper area (hydrologic schemes). When water level decreased in summer or drying season, wetland areas can be divided into different areas based on the presence of standing water (Mitsch and Gosselink 2015). In this study, wetlands were divided into 3 hydrologic zones with a presence of standing water as follows.

1) The intermittently flooded zone (Z1 in Figure 7); the edge of wetland area that located in the outermost of wetland area. This area is shallower than other areas. It is always intermittently flooded by sheet flows in the flooding season.
2) The saturated zone (Z2 in Figure 7); this area was inundated by shallow water. Soils in this area were saturated by water and covered by hydrophyte vegetations.
3) The permanently flooded zone (Z3 in Figure 7); this area is deeper than other areas within wetlands. Thus, the area was inundated all year round and, they were dominated by submerged macrophytes.

In order to spread sampling sites evenly across the wetland, 5 stations were randomly set up around the studied wetlands (Figure 7). Each sampling station comprises of 3 sampling plot that set up across hydrologic schemes of wetlands (Figure 7). Thus, there will be 15 sampling plots in each wetland site. In each sampling plot, soils and vegetations were surveyed and collected. The triangular plot was used for collecting soil samples. Before soil sample was collected in each sampling station, A grid of 1 m^2 was set up in 2 zones – the intermittently flooded zone and saturated zone – for evaluating coverages of vegetation. Plants were identified into family, genus, and species by using the book – Species and distributions of aquatic plants in the northern part of northeastern Thailand (Rodloy et al. 2012). Name of species, genus, and family that showed in this thesis was based on the book – Thai plant names (Smitinand 2001).

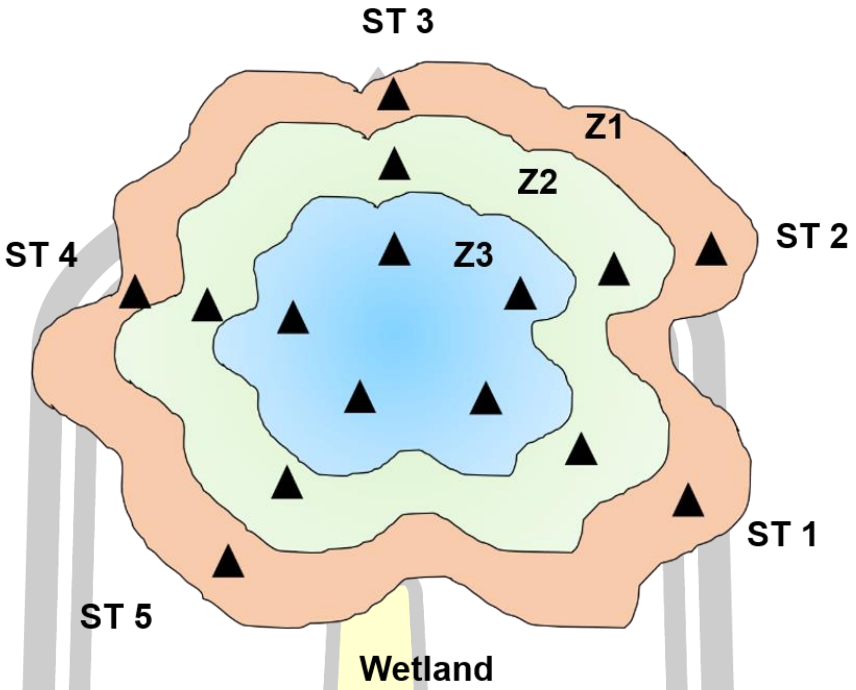


Figure 7 Five random stations (ST 1 – ST 5) were set up across the gradient of inundation in wetlands. Each wetland was identified into three zones with different hydrologic schemes ranging from the driest area (outermost and shallower) to the wettest area (innermost and deeper). The triangular on each hydrologic condition represents a sampling plot for soil samples and vegetation coverages.

3.3 Soil sampling and soil preparation

Soil samples were collected using 2 methods – undisturbed soil structure sampling method and disturbed soil structure sampling method. Composited soil samples (disturbed soil structures) were collected by using hand auger in three of black circle (Figure 8) in order to obtain a triplicate composited sample. At each of black circles, soils were drilled by using hand auger until reach at depth of 50 centimeters. Soil profile was observed and took a photograph, then determined soil color by using Munsell Soil Color Chart. Each of 50-centimeters soil samples was divided into 10 layers (0 – 5, 5 – 10, 10 – 15, 15 – 20, 20 – 25, 25 – 30, 30 – 35, 35 – 40, 40 – 45, and 45 – 50 cm), to observe the change of soil organic carbon concentration throughout soil profiles. Soil samples with similar layer were combined to be a composites sample and packed into plastic bags, before conveying to a laboratory. Undisturbed samples were collected using stainless cores with a diameter of 6.5 cm (Grossman and Reinsch 2002). At the ring circle laying in the center of a triangular plot (Figure 8), the core was pushed into the soil until reach at the depth of 50 centimeters. Then, at the end of two sides of the soil core were sealed by plastic bags and convey to the laboratory. All the soil sample were prepared at the laboratory. For composited samples, soils were air dried at the room temperature for a few days. After moisture in soils were left, the dried samples were ground and passed through a 2 mm sieve for the analysis of soil parameter. However, soil samples were also passed through a 0.5 mm sieve for the analysis of soil organic carbon. The soil samples were packed into plastic bags and keep in the laboratory. The core samples were cleaned and wrapped with aluminum foil. The cores were dried in a hot dry oven under 105 °C in until constants weight was reached or for 48 hours (Craft and Richardson 1993; Grossman and Reinsch 2002). The dried samples were weighed and calculated for soil bulk density, which used for calculating soil carbon stock.

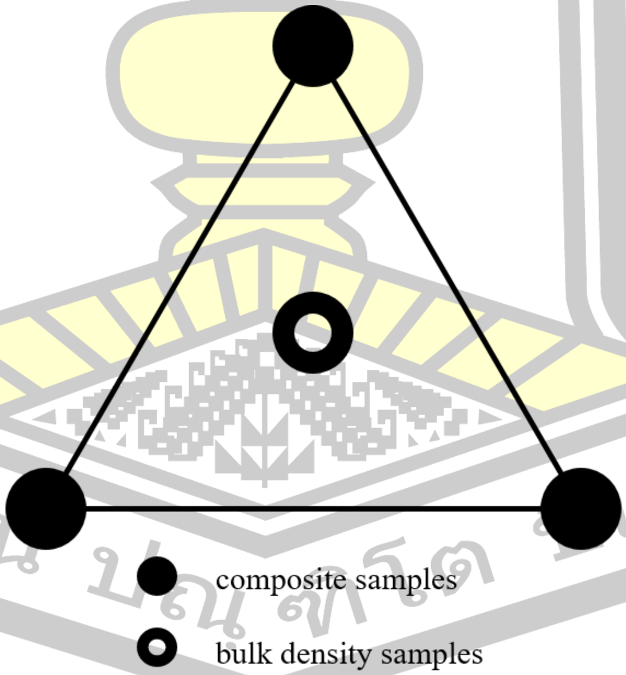


Figure 8 Triangular pattern of soil sampling plot

3.4 Analysis of soil samples

The soil samples from all studied wetlands were analyzed by using the standard of the physical and chemical method to study soil organic carbon and soils parameters as shown in Table 12.

Table 12 Soil parameters and methods of analysis

Soil parameters	**Method of analysis**	**References**
1. Soil color	Munsell color chart	Soil Survey Staff (2014)
2. Soil particle size	Hydrometer	Bouyoucos (1962)
3. Soil reaction (pH)	Glass electrode	Thomas (1996)
4. Soil bulk density	Core method	Blake and Hartage (1986)
5. Soil organic carbon	Wet oxidation	Walkley and Black, (1934)

3.5 Calculation of soil organic carbon

Soil organic carbon concentration (g C kg^{-1}) of each soil depth interval was calculated from Equation 1 (Bernal and Mitsch 2008). The soil carbon stock (C-stock) was calculated by multiplying soil carbon concentration (SOC) by soil bulk density (B.D.) and soil depth interval (depth) as shown in Equation 2 (Batjes 2014).

Equation 1

$$\mathbf{C_{conc.}\ (g\ C\ kg^{-1}) = 10 \times OC_{layer}\ (\%)}$$

Equation 2

$$\mathbf{C\text{-}Stock\ (Mg\ C\ ha^{-1}) = SOC\ (g\ C\ g\ soil^{-1}) \times B.D.\ (g\ m^{-3}) \times depth\ (m)}$$

Where

$C_{conc.}$ ($g\ C\ kg^{-1}$) = Soil organic carbon concentration in each of soil layers

OC_{layers} = Percentage of soil organic carbon derived from soil samples in each soil depth (5 cm intervals) of each soil profile

C-Stock = Soil organic carbon stock or soil organic carbon pool ($Mg\ C\ ha^{-1}$)

SOC = Soil organic carbon content (g C/g soil)

B.D. = Soil bulk density (g/cm^3)

Depth = Depth of soil interval (meter)

3.6 Statistical analysis

Two-ways Analysis of Variance (ANOVA) was used for determining differences of soil organic carbon concentration, with soil depth and three hydrologic conditions as main fixed factors. One-way ANOVA at 95% with Tukey HSD multiple comparison tests was also used in order to find the difference of soil organic carbon pool among wetland sites, three hydrologic zone, and soil depth intervals. Independent sample t-test was used for finding the difference of soil organic carbon stock between upper soil (0 – 25 cm) and lower soil (25 – 50 cm).

CHAPTER 4
RESULTS AND DISCUSSIONS

4.1 Results

4.1.1 Soil textures and particle size distributions

In Bueng Lahan, the percentage of three particle sizes were quite similar. There were five soil textures wetland – clay loam, loam, clay, sandy clay loam, and sandy loam (Table 13). In the intermittently flooded zone, most of the soil profile was dominated by clay loam. Soil textures were sandy loam (0 – 5 cm), sandy clay loam (5 – 10 cm), clay loam (10 – 45 cm), and loam (45 – 50 cm). In the saturated zone, soil texture varied among soil depths. Soil textures were clay loam (0 – 5 cm, 20 – 30 cm, and 40 – 50 cm), clay (5 – 15 cm) and loam (30 – 40 cm). Clay loam was found throughout the soil profile that obtained from the permanently flooded zone.

In Nong Waeng Non-hunting Area, sand particle dominated in three hydrologic zones (Table 14). There were two soil textures that found in the wetland – sandy loam and sandy clay loam. The soil profiles from three hydrologic zones were dominated by sandy loam. In the intermittently flooded zone, soil texture was sandy loam (0 – 30 cm and 40 – 45 cm), sandy clay loam (30 – 40 cm and 45 – 50 cm). In a saturated zone, soil texture was sandy loam (0 – 30 cm and 35 – 45 cm) and sandy clay loam (30 – 35 cm and 45 – 50 cm). In the permanently flooded zone, soil textures were sandy loam (0 – 40 cm) and sandy clay loam (40 – 50 cm).

In Nong Sam Muen, three soil profile was dominated by both sand and clay particle (Table 15). There were three soil textures in the wetland – sandy clay loam, sandy clay, and clay loam. The dominant texture in three hydrologic zones was sandy clay loam. In the intermittently flooded zone, soil textures were sandy clay loam (0 – 30 cm and 35 – 50 cm), and sandy clay (30 – 35 cm). In a saturated zone, soil texture varied widely among soil depth intervals. The texture was sandy clay loam (0 – 15 cm), sandy clay (15 – 35 cm), sandy clay loam (35 – 40 cm), and clay loam (40 – 45 cm). Also, soil texture was clay in 45 – 50 cm depth. In a permanently flooded zone, soils in this area were sandy clay loam.

In Kaeng Lawa, sand and clay particles were slightly dominant in soil profile from three hydrologic zones (Table 16). There were three soil textures in the wetland – clay loam, sandy clay loam, and sandy clay. Soil texture varied widely among soil depth intervals in every hydrologic zone. In the intermittently flooded zone, soil profile comprises many textures, which were sandy clay loam (0 – 5 cm), sandy clay (5 – 25 cm, 30 – 35 cm, and 40 – 45 cm), clay loam (15 – 25 cm, 35 – 40 cm, and 45 – 50 cm). In saturated zone, soil texture was sandy clay loam (0 – 15 cm), clay loam (15 – 30 cm and 35 – 50 cm), and clay (30 – 35 cm). In a permanently flooded zone, soil texture was sandy clay loam (0 – 10 cm, 15 – 20 cm, 30 – 40 cm, and 45 – 50 cm), clay loam (20 – 30 cm and 40 – 45 cm) and sandy clay (10 – 15 cm)

In Huai Suea Ten, the sand particle was dominant in the three soil profiles. As a result, soil texture among three hydrologic zones was almost similar (Table 17). There were two types of soil texture in the wetland – sandy loam and sandy clay loam. In the intermittently flooded zone, textures were sandy loam (0 – 35 cm and 45 – 50 cm), sandy clay loam (35 – 45 cm). In a saturated zone, soil texture was sandy loam throughout soil profile (0 – 50 cm). Likewise, the texture was sandy loam throughout soil profile of the permanently flooded zone.

In Nong Han Kumphawapi, clay and sand particles were dominant in this wetland. Soil texture among three hydrologic zones was similar (Table 18). Soil texture varied among soil depth in each hydrologic zone. There were three type of soil textures in the wetland – clay, sandy clay loam, and sandy clay. In an intermittently flooded zone, soil textures were sandy clay loam (0 – 10 cm) and clay (10 – 50 cm). In the saturated zone, soil textures were clay (0 – 20 cm), sandy clay loam (20 – 35 cm), and sandy clay (35 – 50 cm). In the permanently flooded zone, soil textures were sandy clay (0 – 35 cm), clay (35 – 45 cm), and sandy clay (45 – 50 cm).

In Nong Pla Khun, sand and clay particles were dominant in this wetland. Soil textures among three hydrologic zones were similar, and there were two soil textures in the wetland – sandy clay and sandy clay loam (Table 19). In the intermittently flooded zone, soil texture was sandy clay through soil profile (0 – 50 cm). In saturated zone soil, Textures were sandy clay loam (0 – 5 cm) and sandy clay (5 – 50 cm). In permanently, Textures were sandy clay (0 – 25 cm and 30 – 50 cm), sandy clay loam (25 – 30 cm), and clay loam (35 – 40 cm).

In Bueng Kluea, soil profile in three hydrologic zones was dominated by sand particle (Table 20). There were two types of soil texture in the wetland – sandy clay loam and sandy loam. In the intermittently flooded zone, soil texture was sandy loam (0 – 50 cm). In a saturated zone, Textures were sandy clay loam (0 – 15 cm and 20 – 50 cm) and sandy clay (15 – 20 cm). In a permanently flooded zone, textures were sandy clay loam (0 – 30 cm) and sandy loam (30 – 50 cm).

In Sop Mun-Chi, soil profile in the intermittently flooded zone was dominated by sand particle while others were dominated by clay particle (Table 21). There were three types of soil texture in the wetland – clay, clay loam, and sandy clay loam. Clay texture was dominant in this wetland. In the intermittently flooded zone, soil textures were sandy loam (0 – 25 cm) and clay loam (25 – 50 cm). In the saturated zone, textures were sandy clay loam (0 – 15 cm) and clay (20 – 50 cm). In a permanently flooded zone, textures were clay through soil profile (0 – 50 cm).

Table 13 Soil textures and particle size distribution of Bueng Lahan

Hydrologic Zones	**Soil Layers (cm)**	**Particle Sizes (%)**			**Soil Textures (USDA)**
		Sand	**Silt**	**Clay**	
Intermittently flooded	0 – 5	60.1	23.9	16.1	sandy loam
	5 – 10	50.1	25.9	24.1	sandy clay loam
	10 – 15	42.1	27.9	30.1	clay loam
	15 – 20	40.1	27.9	32.1	clay loam
	20 – 25	36.1	29.9	34.1	clay loam
	25 – 30	34.1	29.9	36.1	clay loam
	30 – 35	34.1	31.9	34.1	clay loam
	35 – 40	30.1	39.9	30.1	clay loam
	40 – 45	30.1	37.9	32.1	clay loam
	45 – 50	34.1	41.9	24.1	loam
Saturated	0 – 5	40.1	27.9	32.1	clay loam
	5 – 10	30.1	29.9	40.1	clay
	10 – 15	30.1	29.9	40.1	clay
	15 – 20	26.1	35.9	38.1	clay loam
	20 – 25	30.1	37.9	32.1	clay loam
	25 – 30	30.1	37.9	32.1	clay loam
	30 – 35	38.9	35.2	25.9	loam
	35 – 40	38.8	35.3	25.9	loam
	40 – 45	26.8	43.3	29.9	clay loam
	45 – 50	26.8	43.3	29.9	clay loam
Permanently flooded	0 – 5	40.8	29.3	29.9	clay loam
	5 – 10	40.8	31.3	27.9	clay loam
	10 – 15	36.8	31.3	31.9	clay loam
	15 – 20	26.8	37.3	35.9	clay loam
	20 – 25	28.8	37.3	33.9	clay loam
	25 – 30	30.8	31.3	37.9	clay loam
	30 – 35	28.8	33.3	37.9	clay loam
	35 – 40	26.8	35.3	37.9	clay loam
	40 – 45	28.8	35.3	35.9	clay loam
	45 – 50	24.8	43.3	31.9	clay loam

Table 14 Soil textures and particle size distribution of Nong Waeng Non-hunting Area

Hydrologic Zones	**Soil Layers (cm)**	**Particle Sizes (%)**			**Soil Textures (USDA)**
		Sand	**Silt**	**Clay**	
Intermittently flooded	0 – 5	71.9	18.4	9.8	sandy loam
	5 – 10	73.9	14.4	11.8	sandy loam
	10 – 15	69.9	12.4	17.8	sandy loam
	15 – 20	69.9	12.4	17.8	sandy loam
	20 – 25	71.9	8.4	19.8	sandy loam
	25 – 30	67.9	12.4	19.8	sandy loam
	30 – 35	68.2	10.0	21.8	sandy clay loam
	35 – 40	68.2	10.0	21.8	sandy clay loam
	40 – 45	70.2	10.0	19.8	sandy loam
	45 – 50	68.2	10.0	21.8	sandy clay loam
Saturated	0 – 5	68.2	14.0	17.8	sandy loam
	5 – 10	72.2	12.0	15.8	sandy loam
	10 – 15	70.2	14.0	15.8	sandy loam
	15 – 20	70.2	12.0	17.8	sandy loam
	20 – 25	68.2	12.0	19.8	sandy loam
	25 – 30	68.2	12.0	19.8	sandy loam
	30 – 35	67.5	10.7	21.8	sandy clay loam
	35 – 40	63.5	16.7	19.8	sandy loam
	40 – 45	65.5	14.7	19.8	sandy loam
	45 – 50	65.5	12.7	21.8	sandy clay loam
Permanently flooded	0 – 5	67.5	14.7	17.8	sandy loam
	5 – 10	69.5	12.7	17.8	sandy loam
	10 – 15	69.5	12.7	17.8	sandy loam
	15 – 20	69.5	14.7	15.8	sandy loam
	20 – 25	69.5	12.7	17.8	sandy loam
	25 – 30	67.5	14.7	17.8	sandy loam
	30 – 35	65.5	14.7	19.8	sandy loam
	35 – 40	65.5	14.7	19.8	sandy loam
	40 – 45	65.5	12.7	21.8	sandy clay loam
	45 – 50	63.5	12.7	23.8	sandy clay loam

Table 15 Soil textures and particle size distribution of Nong Sam Muen

Hydrologic Zones	**Soil Layers (cm)**	**Particle Size (%)**			**Soil Textures (USDA)**
		Sand	**Silt**	**Clay**	
Intermittently flooded	0 – 5	61.0	16.6	22.4	sandy clay loam
	5 – 10	61.0	14.5	24.5	sandy clay loam
	10 – 15	59.7	12.4	27.9	sandy clay loam
	15 – 20	55.7	14.3	30.0	sandy clay loam
	20 – 25	49.7	16.3	34.0	sandy clay loam
	25 – 30	48.1	17.9	34.0	sandy clay loam
	30 – 35	49.9	14.1	36.0	sandy clay
	35 – 40	56.1	9.9	34.0	sandy clay loam
	40 – 45	55.9	14.1	30.0	sandy clay loam
	45 – 50	55.9	14.1	30.0	sandy clay loam
Saturated	0 – 5	53.7	18.3	28.0	sandy clay loam
	5 – 10	51.9	16.1	32.0	sandy clay loam
	10 – 15	49.9	18.1	32.0	sandy clay loam
	15 – 20	45.9	16.1	38.0	sandy clay
	20 – 25	47.9	16.1	36.0	sandy clay
	25 – 30	45.9	18.1	36.0	sandy clay
	30 – 35	39.3	20.8	39.9	clay loam
	35 – 40	45.2	22.9	31.9	sandy clay loam
	40 – 45	40.9	21.2	37.9	clay loam
	45 – 50	38.9	20.8	40.3	clay
Permanently flooded	0 – 5	52.9	18.7	28.3	sandy clay loam
	5 – 10	54.9	18.7	26.3	sandy clay loam
	10 – 15	52.9	20.8	26.3	sandy clay loam
	15 – 20	52.9	16.7	30.3	sandy clay loam
	20 – 25	56.9	14.7	28.3	sandy clay loam
	25 – 30	58.9	12.6	28.5	sandy clay loam
	30 – 35	54.9	16.6	28.5	sandy clay loam
	35 – 40	58.9	14.6	26.5	sandy clay loam
	40 – 45	54.9	14.6	30.5	sandy clay loam
	45 – 50	55.0	16.5	28.5	sandy clay loam

Table 16 Soil textures and particle size distribution of Kaeng Lawa

Hydrologic Zones	**Soil Layers (cm)**	**Particle Sizes (%)**			**Soil Textures (USDA)**
		Sand	**Silt**	**Clay**	
Intermittently flooded	0 – 5	53.4	12.7	33.9	sandy clay loam
	5 – 10	45.4	16.7	37.9	sandy clay
	10 – 15	47.4	16.7	35.9	sandy clay
	15 – 20	43.4	18.7	37.9	clay loam
	20 – 25	39.4	20.7	39.9	clay loam
	25 – 30	37.4	20.7	41.9	clay
	30 – 35	45.4	16.7	37.9	sandy clay
	35 – 40	43.4	18.7	37.9	clay loam
	40 – 45	45.4	16.7	37.9	sandy clay
	45 – 50	43.4	16.7	39.9	clay loam
Saturated	0 – 5	51.4	18.7	29.9	sandy clay loam
	5 – 10	49.4	16.7	33.9	sandy clay loam
	10 – 15	47.4	18.7	33.9	sandy clay loam
	15 – 20	41.4	20.7	37.9	clay loam
	20 – 25	41.4	18.7	39.9	clay loam
	25 – 30	43.4	20.7	35.9	clay loam
	30 – 35	31.6	24.6	43.8	clay
	35 – 40	43.9	22.4	33.8	clay loam
	40 – 45	41.9	22.4	35.8	clay loam
	45 – 50	43.9	22.4	33.8	clay loam
Permanently flooded	0 – 5	45.9	20.4	33.8	sandy clay loam
	5 – 10	47.9	18.4	33.8	sandy clay loam
	10 – 15	45.9	18.4	35.8	sandy clay
	15 – 20	45.9	20.4	33.8	sandy clay loam
	20 – 25	43.9	22.4	33.8	clay loam
	25 – 30	43.9	22.4	33.8	clay loam
	30 – 35	47.9	18.4	33.8	sandy clay loam
	35 – 40	45.9	20.4	33.8	sandy clay loam
	40 – 45	41.6	20.6	37.8	clay loam
	45 – 50	47.6	18.6	33.8	sandy clay loam

Table 17 Soil textures and particle size distribution of Huai Suea Ten

Hydrologic Zones	**Soil Layers (cm)**	**Texture (%)**			**Soil Textures (USDA)**
		Sand	Silt	Clay	
Intermittently flooded	0 – 5	66.1	17.3	16.6	sandy loam
	5 – 10	70.1	13.3	16.6	sandy loam
	10 – 15	68.1	13.3	18.6	sandy loam
	15 – 20	68.1	13.3	18.6	sandy loam
	20 – 25	62.1	19.3	18.6	sandy loam
	25 – 30	66.1	15.3	18.6	sandy loam
	30 – 35	66.1	15.3	18.6	sandy loam
	35 – 40	66.1	13.3	20.6	sandy clay loam
	40 – 45	66.1	13.3	20.6	sandy clay loam
	45 – 50	70.1	13.3	16.6	sandy loam
Saturated	0 – 5	72.1	13.3	14.6	sandy loam
	5 – 10	70.1	13.3	16.6	sandy loam
	10 – 15	70.1	15.3	14.6	sandy loam
	15 – 20	70.1	17.3	12.6	sandy loam
	20 – 25	76.1	15.3	8.6	sandy loam
	25 – 30	76.1	15.3	8.6	sandy loam
	30 – 35	77.4	12.7	9.9	sandy loam
	35 – 40	77.4	12.7	9.9	sandy loam
	40 – 45	75.4	10.7	13.9	sandy loam
	45 – 50	75.4	10.7	13.9	sandy loam
Permanently flooded	0 – 5	73.4	8.7	17.9	sandy loam
	5 – 10	73.4	10.7	15.9	sandy loam
	10 – 15	73.4	12.7	13.9	sandy loam
	15 – 20	71.4	10.7	17.9	sandy loam
	20 – 25	71.4	10.7	17.9	sandy loam
	25 – 30	69.4	12.7	17.9	sandy loam
	30 – 35	67.4	12.7	19.9	sandy loam
	35 – 40	67.4	12.7	19.9	sandy loam
	40 – 45	67.4	12.7	19.9	sandy loam
	45 – 50	69.4	10.7	19.9	sandy loam

Table 18 Soil textures and particle size distribution of Nonghan Kumphawapi

Hydrologic zones	**Soil Layers (cm)**	**Particle Sizes (%)**			**Soil Textures (USDA)**
		Sand	**Silt**	**Clay**	
Intermittently flooded	0 – 5	47.9	25.3	26.8	sandy clay loam
	5 – 10	49.9	21.4	28.7	sandy clay loam
	10 – 15	37.9	21.5	40.6	clay
	15 – 20	31.9	19.5	48.6	clay
	20 – 25	31.9	18.4	49.7	clay
	25 – 30	33.9	13.4	52.7	clay
	30 – 35	35.9	9.5	54.6	clay
	35 – 40	31.9	11.4	56.7	clay
	40 – 45	33.9	8.5	57.6	clay
	45 – 50	31.9	11.4	56.7	clay
Saturated	0 – 5	41.9	0.4	57.7	clay
	5 – 10	39.9	13.5	46.6	clay
	10 – 15	33.9	17.5	48.6	clay
	15 – 20	35.9	15.5	48.6	clay
	20 – 25	49.1	16.1	34.8	sandy clay loam
	25 – 30	55.2	14.0	30.8	sandy clay loam
	30 – 35	55.2	12.0	32.8	sandy clay loam
	35 – 40	53.2	8.0	38.8	sandy clay
	40 – 45	49.2	9.0	41.8	sandy clay
	45 – 50	45.2	10.0	44.8	sandy clay
Permanently flooded	0 – 5	65.2	6.0	28.8	sandy clay loam
	5 – 10	61.2	8.0	30.8	sandy clay loam
	10 – 15	59.2	6.0	34.8	sandy clay loam
	15 – 20	61.2	8.0	30.8	sandy clay loam
	20 – 25	59.2	10.0	30.8	sandy clay loam
	25 – 30	57.2	8.0	34.8	sandy clay loam
	30 – 35	59.2	10.0	30.8	sandy clay loam
	35 – 40	29.5	13.3	57.2	clay
	40 – 45	29.7	13.1	57.2	clay
	45 – 50	53.2	10.0	36.8	sandy clay

Table 19 Soil textures and particle size distribution of Nong Pla Khun

Hydrologic Zones	**Soil Layers (cm)**	**Textures (%)**			**Soil Textures (USDA)**
		Sand	**Silt**	**Clay**	
Intermittently flooded	0 – 5	45.2	14.5	40.3	sandy clay
	5 – 10	45.2	16.9	37.9	sandy clay
	10 – 15	45.2	16.9	37.9	sandy clay
	15 – 20	45.2	14.9	39.9	sandy clay
	20 – 25	47.2	12.9	39.9	sandy clay
	25 – 30	51.2	10.9	37.9	sandy clay
	30 – 35	49.2	12.9	37.9	sandy clay
	35 – 40	49.2	10.9	39.9	sandy clay
	40 – 45	45.2	10.9	43.9	sandy clay
	45 – 50	45.4	13.1	41.6	sandy clay
Saturated	0 – 5	53.5	16.9	29.6	sandy clay loam
	5 – 10	53.7	10.5	35.8	sandy clay
	10 – 15	46.9	15.1	37.9	sandy clay
	15 – 20	47.7	14.4	37.9	sandy clay
	20 – 25	51.7	10.4	37.9	sandy clay
	25 – 30	51.7	10.4	37.9	sandy clay
	30 – 35	48.9	13.1	37.9	sandy clay
	35 – 40	46.9	13.1	39.9	sandy clay
	40 – 45	46.9	11.1	41.9	sandy clay
	45 – 50	46.9	11.1	41.9	sandy clay
Permanently flooded	0 – 5	46.9	13.1	39.9	sandy clay
	5 – 10	46.9	15.1	37.9	sandy clay
	10 – 15	48.9	13.1	37.9	sandy clay
	15 – 20	50.9	13.1	35.9	sandy clay
	20 – 25	48.9	13.1	37.9	sandy clay
	25 – 30	52.9	13.1	33.9	sandy clay loam
	30 – 35	46.9	13.1	39.9	sandy clay
	35 – 40	44.9	15.1	39.9	clay loam
	40 – 45	46.9	13.1	39.9	sandy clay
	45 – 50	48.9	13.1	37.9	sandy clay

Table 20 Soil textures and particle size distribution of Bueng Kluea

Hydrologic Zones	**Soil Layer (cm)**	**Particle Sizes (%)**			**Soil Textures (USDA)**
		Sand	**Silt**	**Clay**	
Intermittently flooded	0 – 5	66.1	16.7	17.2	sandy loam
	5 – 10	66.1	18.7	15.2	sandy loam
	10 – 15	68.1	16.7	15.2	sandy loam
	15 – 20	64.1	20.7	15.2	sandy loam
	20 – 25	64.2	18.6	17.2	sandy loam
	25 – 30	62.2	20.6	17.2	sandy loam
	30 – 35	64.4	18.4	17.2	sandy loam
	35 – 40	64.4	18.4	17.2	sandy loam
	40 – 45	62.4	18.4	19.2	sandy loam
	45 – 50	62.4	20.4	17.2	sandy loam
Saturated	0 – 5	54.4	22.4	23.2	sandy clay loam
	5 – 10	56.4	10.4	33.2	sandy clay loam
	10 – 15	54.1	12.7	33.2	sandy clay loam
	15 – 20	54.1	10.7	35.2	sandy clay
	20 – 25	52.1	18.7	29.2	sandy clay loam
	25 – 30	46.1	22.7	31.2	sandy clay loam
	30 – 35	52.8	19.3	27.9	sandy clay loam
	35 – 40	50.8	19.3	29.9	sandy clay loam
	40 – 45	50.8	21.3	27.9	sandy clay loam
	45 – 50	50.8	19.3	29.9	sandy clay loam
Permanently flooded	0 – 5	56.8	11.3	31.9	sandy clay loam
	5 – 10	54.8	13.3	31.9	sandy clay loam
	10 – 15	52.8	15.3	31.9	sandy clay loam
	15 – 20	54.8	13.3	31.9	sandy clay loam
	20 – 25	52.8	23.3	23.9	sandy clay loam
	25 – 30	54.8	21.3	23.9	sandy clay loam
	30 – 35	56.8	23.3	19.9	sandy loam
	35 – 40	56.8	23.3	19.9	sandy loam
	40 – 45	54.8	25.3	19.9	sandy loam
	45 – 50	56.8	23.3	19.9	sandy loam

Table 21 Soil textures and particle size distribution of Sop Mun-Chi

Hydrologic Zones	**Soil Layers (cm)**	**Particle Sizes (%)**			**Soil Textures (USDA)**
		Sand	**Silt**	**Clay**	
Intermittently flooded	0 – 5	47.0	23.8	29.2	sandy clay loam
	5 – 10	50.0	22.7	27.3	sandy clay loam
	10 – 15	54.0	18.7	27.3	sandy clay loam
	15 – 20	54.0	17.7	28.3	sandy clay loam
	20 – 25	46.0	24.7	29.3	sandy clay loam
	25 – 30	40.0	24.7	35.3	clay loam
	30 – 35	40.0	26.7	33.3	clay loam
	35 – 40	44.0	22.7	33.3	clay loam
	40 – 45	34.0	26.7	39.3	clay loam
	45 – 50	40.0	20.7	39.3	clay loam
Saturated	0 – 5	64.0	14.6	21.4	sandy clay loam
	5 – 10	48.0	20.7	31.3	sandy clay loam
	10 – 15	46.0	19.7	34.3	sandy clay loam
	15 – 20	34.0	22.7	43.3	clay
	20 – 25	22.5	24.6	52.9	clay
	25 – 30	23.4	25.5	51.1	clay
	30 – 35	25.4	23.6	51.0	clay
	35 – 40	25.4	25.6	49.0	clay
	40 – 45	24.4	24.6	51.0	clay
	45 – 50	25.4	25.6	49.0	clay
Permanently flooded	0 – 5	30.4	22.7	47.0	clay
	5 – 10	30.4	20.7	49.0	clay
	10 – 15	28.4	24.7	46.9	clay
	15 – 20	28.4	24.7	47.0	clay
	20 – 25	28.4	22.7	49.0	clay
	25 – 30	30.4	21.7	48.0	clay
	30 – 35	28.4	22.7	48.9	clay
	35 – 40	26.4	22.7	50.9	clay
	40 – 45	29.1	21.3	49.6	clay
	45 – 50	29.1	22.4	48.6	clay

4.1.2 Soil bulk densities

Soil bulk densities varied widely among wetland sites, as well as among three hydrologic zones (Table 22). In the intermittently flooded zone, soil bulk densities ranged from 0.23 to 1.88 g cm^{-3} among wetland sites. Nong Waeng Non-hunting Area (NW) had the highest soil bulk density while Nonghan Kumphawapi (HK) had the lowest soil bulk density. This value was lower than other soil bulk densities that obtained from all wetland sites. In the saturated zone, soil bulk densities ranged from 1.10 to 1.92 g cm^{-3} among wetland sites. Bueng Kluea (BK) had the lowest soil bulk density while the highest bulk density obtained from Huai Suea Ten (ST). The soil bulk densities measured from both Kaeng Lawa (NW) and Nong Waeng Non-hunting Area (NW) also had high values. In the permanently flooded zone, soil bulk densities ranged from 1.24 to 1.92 g cm^{-3}. The highest value obtained from Huai Suea Ten while the lowest value derived from Nong Sam Muen. The soil bulk densities in three hydrologic zones of Nong Waeng Non-hunting Area were slightly similar (Table 22). Kaeng Lawa showed high bulk densities in the saturated and permanently flooded zone. Similarly, Huai Suea Ten showed high soil bulk densities in both saturated and permanently flooded zone.

Table 22 Soil bulk density among hydrologic schemes in freshwater wetlands

Wetlands	**Bulk density (g cm^{-3})**		
	Intermittent	**Saturated**	**Permanent**
LH	1.42 ± 0.14	1.42 ± 0.23	1.33 ± 0.09
NW	1.88 ± 0.32	1.80 ± 0.20	1.84 ± 0.13
SM	1.73 ± 0.09	1.21 ± 0.34	1.24 ± 0.30
LW	1.48 ± 0.15	1.80 ± 0.22	1.91 ± 0.04
ST	1.46 ± 0.25	1.92 ± 0.28	1.92 ± 0.26
HK	0.23 ± 0.05	1.15 ± 0.14	1.42 ± 0.16
PK	1.67 ± 0.15	1.38 ± 0.08	1.47 ± 0.11
BK	1.45 ± 0.14	1.10 ± 0.24	1.59 ± 0.32
MC	1.43 ± 0.07	1.65 ± 0.10	1.48 ± 0.07

Remarks: Intermittent = intermittently flooded zone, saturated = saturated zone, and permanent = permanently flooded zone. LH = Bueng Lahan, NW = Nong Waeng Non-hunting Area, SM = Nong Sam Muen, LW = Kaeng Lawa, ST = Huai Suea Ten, HK = Nonghan Kumpawapi, PK = Nong Pla Khun, and MC = Sop Mun-Chi

4.1.3 Vegetation coverages

Approximately 33 species in 21 families were found in all freshwater wetlands of the Chi River Basin (Table 23). Huai Suea Ten showed the highest number of family while the lowest number was observed in 3 wetland sites including Bueng Lahan, Nong Waeng Non-hinting Area, and Bueng Kluea. The highest number of species (species richness) was also observed in Huai Suea Ten, while the lowest species richness was observed in Bueng Kluea (Table 23). The species richness and number of family in the saturated zone in many wetland sites in this study tend to be higher than those of the intermittently flooded zone. However, the total numbers of species in the intermittently flooded zone were higher than those of the saturated zone (Table 8).

The dominated group of vegetation in the freshwater wetlands of this study included 5 of Families including Poaceae, Cyperaceae, Fabaceae, Convolvulaceae, and Nelumbonaceae (Table 25). The most areas of the freshwater wetland in this study were dominated by five species including *Brachiaria mutica* (Forssk.) Stapf., *Cyperus* spp., *Ipomoea aquatica* Forssk., *Panicum repens* L., and *Cynodon dactylon* (L.) Pers. (Table 26). In the intermittently flooded zone, five species wildly covering on wetland area included *Brachiaria mutica* (Forssk.) Stapf. (Poaceae), *Cynodon dactylon* (L.) Pers., *Mimosa pigra* L., *Ipomoea aquatica* Forssk., *Acacia auriculiformis* A. Cunn. ex Benth., and *Barringtonia acutangula* (L.) Gaertn. In the saturated zone, five species that mostly covering on this surface included *Brachiaria mutica* (Forssk.) Stapf., *Cyperus* spp., *Nelumbo nucifera* Gaertn., *Ipomoea aquatica* Forssk., and *Panicum repens* L.

Most of the macrophytes found in all freshwater wetlands were the herbaceous and graminoid group. However, shrubs or tree were occasionally found in some wetland sites. The habit of these was either emergent or floating macrophytes, which can be mostly found in both intermittently flooded and saturated zone. The floating group was also stranded aground and found in the saturated zone. However, each wetland sites had different species that dominated in their area as well as their hydrologic zones. The details were as followed.

In Bueng Lahan, the most areas were dominated by *Nelumbo nucifera* Gaertn., and *Cynodon dactylon* (L.) Pers. and *Phragmites* spp. (Table 27). In the intermittently flooded zone of this wetland, both *Cynodon dactylon* (L.) Pers. and *Phragmites* spp. dominated in this area. In the saturated zone, *Nelumbo nucifera* Gaertn. obviously dominated in this area.

In Nong Waeng Non-hunting Area, surrounding areas of wetlands were dominated by *Acacia auriculiformis* A. Cunn. ex Benth. However, two species (*Brachiaria mutica* (Forssk.) Stapf. and *Panicum repens* L.) dominated in the edge of the wetland area. The intermittently flooded zone of this wetland was dominated by both *Paspalum* sp. and *Wedelia trilobata* (L.) Hitchc., while the saturated zone was dominated by both *Brachiaria mutica* (Forssk.) Stapf. and *Panicum repens* L.

In Nong Sam Muen, two species (*Brachiaria mutica* (Forssk.) Stapf. and *Mimosa pigra* L.) dominate in this wetland. The intermittently flooded zone of this wetland was dominated by three species including *Mimosa pigra* L., *Brachiaria mutica* (Forssk.) Stapf., *Cynodon dactylon* (L.) Pers., while the saturated zone was dominated by *Salvinia cucullata* Roxb. ex Bory, *Typha angustifolia* L., *Brachiaria mutica* (Forssk.) Stapf.

In Kaeng Lawa, three species (*Panicum repens* L., *Cynodon dactylon* (L.) Pers., *Cyperus* spp.) dominate in this wetland. The intermittently flooded zone of this wetland was dominated by three species including *Cynodon dactylon* (L.) Pers, *Cyperus* spp., and *Oryza sativa* L. The saturated zone was dominated by both *Panicum repens* L. and *Brachiaria mutica* (Forssk.) Stapf.

In Huai Suea Ten, dominant species of this wetland include three species including *Brachiaria mutica* (Forssk.) Stapf, *Acacia auriculiformis* A. Cunn. ex Benth, and *Cyperus* spp. The intermittently flooded zone of this wetland was dominated by both *Acacia auriculiformis* A. Cunn. ex Benth. and *Brachiaria mutica* (Forssk.) Stapf. The saturated zone was dominated by *Cyperus* spp., *Brachiaria mutica* (Forssk.) Stapf., and *Phragmites* spp.

In Nonghan Kumphawapi, *Ipomoea aquatica* Forssk., *Brachiaria mutica* (Forssk.) Stapf., and *Mimosa pigra* L. dominated in this wetland area. The intermittently flooded zone was dominated by both *Mimosa pigra* L. and

Brachiaria mutica (Forssk.) Stapf. The saturated zone was dominated by *Ipomoea aquatica* Forssk., Cyperus spp., and *Brachiaria mutica* (Forssk.) Stapf.

In Nong Pla Khun, *Brachiaria mutica* (Forssk.) Stapf. dominated in this area. The intermittently flooded zone was dominated by three species including *Brachiaria mutica* (Forssk.) Stapf., *Panicum repens* L., and *Croton crassifolius* Geiseler. The saturated zone was dominated by *Brachiaria mutica* (Forssk.) Stapf., *Nelumbo nucifera* Gaertn., respectively.

In Bueng Kluea, three species including *Ipomoea aquatica* Forssk, *Nelumbo nucifera* Gaertn., and *Brachiaria mutica* (Forssk.) Stapf., dominate in this wetland. The intermittently flooded zone was dominated by *Ipomoea aquatica* Forssk. and *Brachiaria mutica* (Forssk.) Stapf., respectively. The saturated zone was dominated by *Nelumbo nucifera* Gaertn. and *Ipomoea aquatica* Forssk., respectively.

In Sop Mun-Chi, both *Cyperus* sp. and *Barringtonia acutangula* (L.) Gaertn. dominate in this area. The intermittently flooded zone was dominated by *Nelumbo nucifera* Gaertn. and *Ipomoea aquatica* Forssk., respectively. The saturated zone was dominated by *Cyperus* spp. and *Barringtonia acutangula* (L.) Gaertn.

Table 23 The number of family and species of vegetation in wetlands in this study

Wetland sites	**Number of Family**	**Number of Genus**	**Number of Species**
LH	7	7	9
NW	7	7	10
SM	9	9	11
LW	3	3	7
ST	10	10	14
HK	9	9	11
PK	8	8	11
BK	7	7	5
MC	8	8	9
All sites	**21**	**21**	**33**

Remarks: The number of species and families based on surveying in the sampling area. LH = Bueng Lahan, NW = Nong Waeng Non-hunting Area, SM = Nong Sam Muen, LW = Kaeng Lawa, ST = Huai Suea Ten, HK = Nonghan Kumpawapi, PK = Nong Pla Khun, and MC = Sop Mun-Chi

Table 24 The number of family and species of vegetation in different hydrologic conditions of each freshwater wetlands in this study

Wetland sites	**Number of family**		**Number of genus**		**Number of species**	
	Intermittent	**Saturate**	**Intermittent**	**Saturate**	**Intermittent**	**Saturate**
Bueng Lahan	3	6	4	6	4	6
Nong Waeng Non-hunting Area	3	5	5	6	5	6
Nong Sam Muen	5	8	6	9	6	9
Kaeng Lawa	2	3	5	5	5	5
Huai Suea Ten	7	5	9	7	9	7
Nonghan Kumphawapi	5	9	6	10	6	10
Nong Pla Khun	5	7	8	7	8	7
Bueng Kluea	3	5	4	5	4	5
Sop Mun-Chi	6	7	6	7	6	7
All areas	**16**	**16**	**26**	**23**	**26**	**23**

Remarks: The number of species and families based on surveying in the sampling area.

Table 25 The hydrophyte species that found in freshwater wetlands in the Chi River Basin

No.	Thai name	Common name	Scientific name	Family	Habit	Coverages (%)	Frequency
1.	Ya khon	Buffalo grass	*Brachiaria mutica* (Forssk.) Stapf	Poaceae	Em	15.64	22
2.	Kok	Sedge	*Cyperus* spp.	Cyperaceae	Em	9.75	21
3.	Phak bung thai	Swamp morning glory	*Ipomoea aquatica* Forssk.	Convolvulaceae	Em	8.57	22
4.	Ya channakat	Torpedo grass	*Panicum repens* L.	Poaceae	Em	6.74	15
5.	Ya phraek	Bermuda grass	*Cynodon dactylon* (L.) Pers.	Poaceae	Em	5.48	10
6.	Bua luang	Indian lotus	*Nelumbo nucifera* Gaertn.	Nelumbonaceae	Fl	5.45	12
7.	Maiyarap yak	Giant sensitive tree	*Mimosa pigra* L.	Fabaceae	Em	4.90	9
8.	Chik nam	Indian oak	*Barringtonia acutangula* (L.) Gaertn.	Lecythidaceae	Em	4.30	5
9.	Kra thin narong	Earleaf Acacia	*Acacia auriculiformis* A. Cunn. ex Benth.	Fabaceae	Em	3.80	6
10.	Ya khaem	Common reed	*Phragmites* spp.	Poaceae	Em	3.00	4
11.	Chok hu nu	Asian watermoss	*Salvinia cucullata* Roxb. ex Bory	Salviniaceae	Fl	2.65	5
12.	Ueang phet ma	Smartweed	*Persicaria* spp.	Polygonaceae	Em	2.44	9
13.	Khao	Rice	*Oryza sativa* L.	Poaceae	Em	1.85	2
14.	Phak top chawa	Water hyacinth	*Eichhornia crassipes* (Mart.) Solms	Pontederiaceae	Fl	1.40	6
15.	Thup ruesi	Cattail	*Typha angustifolia* L.	Typhaceae	Em	1.40	2
16.	Kradum thong lueai	-	*Wedelia trilobata* (L.) Hitchc.	Asteraceae	Em	1.00	1
18.	Fai nam	-	*Croton crassifolius* Geiseler	Euphobiaceae	Em	0.95	2

Table 25 (continued)

No.	**Thai name**	**Common name**	**Scientific name**	**Family**	**Habits**	**Coverages (%)**	**Frequency**
19.	Bon	Cocoyam	*Colocasia esculenta* (L.) Schott	Araceae	Em	0.90	3
20.	Phak bia yai	Common garden purslane	*Portulaca oleracea* L.	Portularcaceae	Em	0.80	1
21.	Phak krachet	Water Mimosa	*Neptunia* spp.	Fabaceae	Em	0.70	2
22.	Phai	Bamboo	*Bambusa* spp.	Poaceae	Em	0.55	2
23.	Haeo song kra thiam	Water chestnut	*Eleocharis dulcis* (Burm. f.) Trin. ex. Hensch.	Cyperaceae	Em	0.52	2
24.	Ma kham thet	Manila tamarind	*Pithecellobium dulce* (Roxb.) Benth.	Fabaceae	Em	0.50	1
25.	Siao lek	-	*Phyllanthus taxodiifolius* Beille	Phyllanthraceae	Em	0.50	2
26.	Ya nguang chang	Indian heliotrope	*Heliotropium indicum* L.	Boraginaceae	Em	0.40	2
27.	Bua	water lily	*Nymphaea* spp.	Nymphaceae	Fl	0.35	2
28.	Khoi	Siamese rough bush	*Streblus asper* Lour.	Moraceae	Em	0.20	1
29.	Nam phung do	-	*Azima sarmentosa* (Blume) Benth. & Hook. f.	Salvadoraceae	Em	0.20	1
30.	Phaeng phuai	Water Primrose	*Ludwigia adscendens* (L.) H. Hara	Onagraceae	Em	0.20	2
31.	Fern	Fern	*Nephrolepis* sp.	Lomariopsidaceae	Em	0.10	1
32.	Hu ling	-	*Hymenocardia punctata* Wall. ex Lindl.	Phyllanthraceae	Em	0.10	1
33.	Lao	Wild cane	*Saccharum spontaneum* L.	Poaceae	Em	0.10	1
Total coverages						**86.44**	

Remarks: Em = emergent macrophytes, Fl = floating macrophytes

Table 26 Percentage of vegetation coverage in freshwater wetlands of Chi River Basin

Species	Common name	Coverage of each species on wetland sites (%)									Frequency
		BK	HK	LH	LW	MC	NW	PK	SM	ST	
Brachiaria mutica (Forssk.) Stapf	Buffalo grass	12.0	21.0		10.0	2.0	18.4	52.0	19.0	22.0	8
Cyperus spp.	Sedge	8.5	11.0	7.0	12.0	26.0		7.0	10.0	16.0	8
Ipomoea aquatica Forssk.	Swamp morning glory	41.5	24.0	4.0	–	–	3.2	6.0	2.0	5.0	7
Panicum repens L.	Torpedo grass	1.5	–	1.0	25.9	6.0	18.5	8.5	–	6.0	7
Cynodon dactylon (L.) Pers.	Bermuda grass	–	–	28.0	13.8	–	–	1.0	10.0	2.0	5
Nelumbo nucifera Gaertn.	Indian lotus	16.5	–	31.0	–	–	–	5.0	2.0	–	4
Mimosa pigra L.	Giant sensitive tree	–	18.0	–	–	4.0	–	9.0	18.0	–	4
Barringtonia acutangula (L.) Gaertn.	Indian oak	–	–	–	–	43.0	–	–	–	–	1
Acacia auriculiformis A. Cunn. ex Benth.	Earleaf Acacia	–	–	–	–	–	20.0	–	–	18.0	2
Phragmites spp.	Common reed	–	5.0	15.0	–	–	–	–	–	10.0	3
Salvinia cucullata Roxb. ex Bory	Asian watermoss	–	–	8.0	–	–	8.0	0.5	10.0		4
Persicaria spp.	Smartweed	–	3.0	–		6.0	0.4	–	13.0	2.0	5
Oryza sativa L.	Rice	8.5	–	–	10.0	–	–	–	–	–	2
Eichhornia crassipes (Mart.) Solms	Water hyacinth	3.0	4.0	–	–	–	–	1.0	6.0	–	4
Typha angustifolia L.	Cattail	–	–	5.0	–	–	–	–	9.0	–	2
Paspalum sp.	Grass	–	–	–	–	–	10.0	–	–	–	1
Wedelia trilobata (L.) Hitchc.	-	–	–	–	–	–	10.0	–	–	–	1
Croton crassifolius Geiseler	-	–	–	–	–	–	–	7.5	–	2.0	2
Colocasia esculenta (L.) Schott	Cocoyam	–	5.0	–	–	–	–	–	–	4.0	2
Portulaca oleracea L.	Common garden purslane	–	–	–	–	8.0	–	–	–	–	1

Table 26 (continued)

Species	Common name	Coverage of each species on wetland sites (%)									Frequency
		BK	HK	LH	LW	MC	NW	PK	SM	ST	
Bambusa spp.	Bamboo	–	–	–	–	–	–	2.5	–	3.0	2
Eleocharis dulcis (Burm. f.) Trin. ex. Hensch.	Water chestnut	–	–	–	5.2	–	–	–	–	–	1
Phyllanthus taxodiifolius Beille	-	–	–	–	–	–	–	–	–	5.0	1
Pithecellobium dulce (Roxb.) Benth.	Manila tamarind	–	–	–	–	–	5.0	–	–	–	1
Heliotropium indicum L.	Indian heliotrope	–	–	–	–	4.0	–	–	–	–	1
Nymphaea spp.	Water lily	–	–	–	3.0	–	0.5	–	–	–	2
Azima sarmentosa (Blume) Benth. & Hook. f.	-	–	–	–	–	–	–	–	–	2.0	1
Ludwigia adscendens (L.) H. Hara	Water Primrose	–	1.0	1.0	–	–	–	–	–	–	2
Streblus asper Lour.	Siamese rough bush	–	–	–	–	–	–	–	–	2.0	1
Hymenocardia punctata Wall. ex Lindl.	-	–	–	–	–	1.0	–	–	–	–	1
Nephrolepis sp.	Fern	–	1.0	–	–	–	–	–	–	–	1
Saccharum spontaneum L.	Wild cane	–	–	–	–	–	–	–	1.0	–	1
Total coverage (%)		**91.5**	**100.0**	**100.0**	**79.9**	**100.0**	**94.0**	**100.0**	**100.0**	**99.0**	–
Species richness		**7**	**11**	**9**	**7**	**9**	**10**	**11**	**11**	**14**	–

Remarks: LH = Bueng Lahan, NW = Nong Waeng Non-hunting Area, SM = Nong Sam Muen, LW = Kaeng Lawa, ST = Huai Suea Ten, HK = Nonghan Kumpawapi, PK = Nong Pla Khun, and MC = Sop Mun-Chi

Table 27 The hydrophyte species that found in Bueng Lahan

No.	**Common name**	**Species**	**Family**	**Habit**	**Coverage (%)**	**Frequency**
1.	Indian lotus	*Nelumbo nucifera* Gaertn.	Nelumbonaceae	Floating	31.0	5
2.	Bermuda grass	*Cynodon dactylon* (L.) Pers.	Poaceae	Emergent	28.0	3
3.	Common reed	*Phragmites* spp.	Poaceae	Emergent	15.0	2
4.	Asian watermoss	*Salvinia cucullata* Roxb. ex Bory	Salviniaceae	Floating	8.0	2
5.	Sedge	*Cyperus* spp.	Cyperaceae	Emergent	7.0	3
6.	Cattail	*Typha angustifolia* L.	Typhaceae	Emergent	5.0	1
7	Swamp morning glory	*Ipomoea aquatica* Forssk.	Convolvulaceae	Emergent	4.0	1
8	Torpedo grass	*Panicum repens* L.	Poaceae	Emergent	1.0	1
9	Water Primrose	*Ludwigia adscendens* (L.) H. Hara	Onagraceae	Emergent	1.0	1
	Total				**100.0**	–

Table 28 The hydrophyte species that found in Nong Waen Non-hunting Area

No.	Common name	Species	Family	Habit	Coverage (%)	Frequency
1.	Earleaf Acacia	*Acacia auriculiformis* A. Cunn. ex Benth.	Fabaceae	Emergent	20.0	2
2.	Torpedo grass	*Panicum repens* L.	Poaceae	Emergent	18.5	3
3.	Buffalo grass	*Brachiaria mutica* (Forssk.) Stapf	Poaceae	Emergent	18.4	2
4.	Grass	*Paspalum* sp.	Poaceae	Emergent	10.0	1
5.	–	*Wedelia trilobata* (L.) Hitchc.	Asteraceae	Emergent	10.0	1
6.	Asian watermoss	*Salvinia cucullata* Roxb. ex Bory	Salviniaceae	Floating	8.0	1
7.	Manila tamarind	*Pithecellobium dulce* (Roxb.) Benth.	Fabaceae	Emergent	5.0	1
8.	Swamp morning glory	*Ipomoea aquatica* Forssk.	Convolvulaceae	Emergent	3.2	2
9.	Water lily	*Nymphaea* spp.	Nymphaceae	Floating	0.5	1
10.	Smartweed	*Persicaria* spp.	Polygonaceae	Emergent	0.4	1
	Total				**94.0**	–

Table 29 The hydrophyte species that found in Nong Sam Muen

No.	Common name	Species	Family	Habit	Coverage (%)	Frequency
1.	Buffalo grass	*Brachiaria mutica* (Forssk.) Stapf	Poaceae	Emergent	19.0	2
2.	Giant sensitive tree	*Mimosa pigra* L.	Fabaceae	Emergent	18.0	2
3.	smartweed	*Persicaria* spp.	Polygonaceae	Emergent	13.0	2
4.	Asian watermoss	*Salvinia cucullata* Roxb. ex Bory	Salviniaceae	Floating	10.0	1
5.	Bermuda grass	*Cynodon dactylon* (L.) Pers.	Poaceae	Emergent	10.0	2
6.	Sedge	*Cyperus* spp.	Cyperaceae	Emergent	10.0	3
7.	Cattail	*Typha angustifolia* L.	Typhaceae	Emergent	9.0	1
8.	Water hyacinth	*Eichhornia crassipes* (Mart.) Solms	Pontederiaceae	Floating	6.0	3
9.	Indian lotus	*Nelumbo nucifera* Gaertn.	Nelumbonaceae	Floating	2.0	1
10.	Swamp morning glory	*Ipomoea aquatica* Forssk.	Convolvulaceae	Emergent	2.0	2
11.	Wild cane	*Saccharum spontaneum* L.	Poaceae	Emergent	1.0	1
	Total				**100.0**	–

Table 30 The hydrophyte species that found in Kaeng Lawa

No.	Common name	Species	Family	Habit	Coverage (%)	Frequency
1.	Torpedo grass	*Panicum repens* L.	Poaceae	Emergent	25.9	6
2.	Bermuda grass	*Cynodon dactylon* (L.) Pers.	Poaceae	Emergent	13.8	3
3.	Sedge	*Cyperus* spp.	Cyperaceae	Emergent	12.0	2
4.	Buffalo grass	*Brachiaria mutica* (Forssk.) Stapf	Poaceae	Emergent	10.0	1
5.	Rice	*Oryza sativa* L.	Poaceae	Emergent	10.0	1
6.	Water chestnut	*Eleocharis dulcis* (Burm. f.) Trin. ex. Hensch.	Cyperaceae	Emergent	5.2	2
7.	Water lily	*Nymphaea* spp.	Nymphaceae	Floating	3.0	1
	Total				**79.9**	–

Table 31 The hydrophyte species that found in Huai Suea Ten

No.	Common name	Species	Family	Habit	Coverage (%)	Frequency
1.	Buffalo grass	*Brachiaria mutica* (Forssk.) Stapf	Poaceae	Emergent	22.0	3.0
2.	Earleaf Acacia	*Acacia auriculiformis* A. Cunn. ex Benth.	Fabaceae	Emergent	18.0	4.0
3.	Sedge	*Cyperus* spp.	Cyperaceae	Emergent	16.0	2.0
4.	Common reed	*Phragmites* spp.	Poaceae	Emergent	10.0	1.0
5.	Torpedo grass	*Panicum repens* L.	Poaceae	Emergent	6.0	2.0
6.	–	*Phyllanthus taxodiifolius* Beille	Phyllanthraceae	Emergent	5.0	2.0
7.	Swamp morning glory	*Ipomoea aquatica* Forssk.	Convolvulaceae	Emergent	5.0	1.0
8.	Cocoyam	*Colocasia esculenta* (L.) Schott	Araceae	Emergent	4.0	1.0
9.	Bamboo	*Bambusa* spp.	Poaceae	Emergent	3.0	1.0
10.	–	*Azima sarmentosa* (Blume) Benth. & Hook. f.	Salvadoraceae	Emergent	2.0	1.0
11.	–	*Croton crassifolius* Geiseler	Euphobiaceae	Emergent	2.0	1.0
12.	Bermuda grass	*Cynodon dactylon* (L.) Pers.	Poaceae	Emergent	2.0	1.0
13.	Siamese rough bush	*Streblus asper* Lour.	Moraceae	Emergent	2.0	1.0
14.	Smartweed	*Persicaria* spp.	Polygonaceae	Emergent	2.0	1.0
	Total				**99.0**	–

Table 32 The hydrophyte species that found in Nonghan Kumphawapi

No.	**Common name**	**Species**	**Family**	**Habit**	**Coverage (%)**	**Frequency**
1.	Swamp morning glory	*Ipomoea aquatica* Forssk.	Convolvulaceae	Emergent	24.0	5
2.	Buffalo grass	*Brachiaria mutica* (Forssk.) Stapf	Poaceae	Emergent	21.0	4
3.	Giant sensitive tree	*Mimosa pigra* L.	Fabaceae	Emergent	18.0	4
4.	Sedge	*Cyperus* spp.	Cyperaceae	Emergent	11.0	2
5.	Water Mimosa	*Neptunia* spp.	Fabaceae	Emergent	7.0	2
6.	Cocoyam	*Colocasia esculenta* (L.) Schott	Araceae	Emergent	5.0	2
7.	Common reed	*Phragmites* spp.	Poaceae	Emergent	5.0	1
8.	Water hyacinth	*Eichhornia crassipes* (Mart.) Solms	Pontederiaceae	Floating	4.0	1
9.	Smartweed	*Persicaria* spp.	Polygonaceae	Emergent	3.0	2
10.	Fern	*Nephrolepis* sp.	Lomariopsidaceae	Emergent	1.0	1
11.	Water Primrose	*Ludwigia adscendens* (L.) H. Hara	Onagraceae	Emergent	1.0	1
	Total				**100.0**	–

Table 33 The hydrophyte species that found in Nong Pla Khun

No.	Common name	Species	Family	Habit	Coverage (%)	Frequency
1.	Buffalo grass	*Brachiaria mutica* (Forssk.) Stapf	Poaceae	Emergent	52.0	7
2.	Giant sensitive tree	*Mimosa pigra* L.	Fabaceae	Emergent	9.0	2
3.	Torpedo grass	*Panicum repens* L.	Poaceae	Emergent	8.5	1
4.	–	*Croton crassifolius* Geiseler	Euphobiaceae	Emergent	7.5	1
5.	Sedge	*Cyperus* spp.	Cyperaceae	Emergent	7.0	2
6.	Swamp morning glory	*Ipomoea aquatica* Forssk.	Convolvulaceae	Emergent	6.0	3
7.	Indian lotus	*Nelumbo nucifera* Gaertn.	Nelumbonaceae	Floating	5.0	2
8.	Bamboo	*Bambusa* spp.	Poaceae	Emergent	2.5	1
9.	Bermuda grass	*Cynodon dactylon* (L.) Pers.	Poaceae	Emergent	1.0	1
10.	Water hyacinth	*Eichhornia crassipes* (Mart.) Solms	Pontederiaceae	Floating	1.0	1
11.	Asian watermoss	*Salvinia cucullata* Roxb. ex Bory	Salviniaceae	Floating	0.5	1
					100.0	–

Table 34 The hydrophyte species that found in Bueng Kluea

No.	Common name	Species	Family	Habit	Coverage (%)	Frequency
1.	Swamp morning glory	*Ipomoea aquatica* Forssk.	Convolvulaceae	Emergent	41.5	8
2.	Indian lotus	*Nelumbo nucifera* Gaertn.	Nelumbonaceae	Floating	16.5	4
3.	Buffalo grass	*Brachiaria mutica* (Forssk.) Stapf	Poaceae	Emergent	12.0	2
4.	Rice	*Oryza sativa* L.	Poaceae	Emergent	8.5	1
5.	Sedge	*Cyperus* spp.	Cyperaceae	Emergent	8.5	2
6.	Water hyacinth	*Eichhornia crassipes* (Mart.) Solms	Pontederiaceae	Floating	3.0	1
7.	Torpedo grass	*Panicum repens* L.	Poaceae	Emergent	1.5	1
	Total				**91.5**	

Table 35 The hydrophyte species that found in Sop Mun-Chi

No.	Common name	Species	Family	Habit	Coverage (%)	Frequency
1.	Indian oak	*Barringtonia acutangula* (L.) Gaertn.	Lecythidaceae	Emergent	43.0	5
2.	Sedge	*Cyperus* spp.	Cyperaceae	Emergent	26.0	5
3.	Common garden purslane	*Portulaca oleracea* L.	Portularcaceae	Emergent	8.0	1
4.	Smartweed	*Persicaria* spp.	Polygonaceae	Emergent	6.0	3
5.	Torpedo grass	*Panicum repens* L.	Poaceae	Emergent	6.0	1
6.	Indian heliotrope	*Heliotropium indicum* L.	Boraginaceae	Emergent	4.0	2
7.	Giant sensitive tree	*Mimosa pigra* L.	Fabaceae	Emergent	4.0	1
8.	Buffalo grass	*Brachiaria mutica* (Forssk.) Stapf	Poaceae	Emergent	2.0	1
9.	–	*Hymenocardia punctata* Wall. ex Lindl.	Phyllanthraceae	Emergent	1.0	1
	Total				**100.0**	–

4.1.4 Soil reaction (soil pH)

In Bueng Lahan, the soil pH obtained from three soil profile increase with increasing depth (Figure 9). The permanently flooded zone had higher soil pH than did other hydrologic zones, ranging from 6.0 to 6.7 (moderately acid – neutral). The intermittently flooded zone had the lowest soil pH, ranging between 5.0 and 5.3 (very strongly acid – strongly acid). The soil pH in the saturated zone ranged from 5.5 to 6.3 (strongly acid – slightly acid).

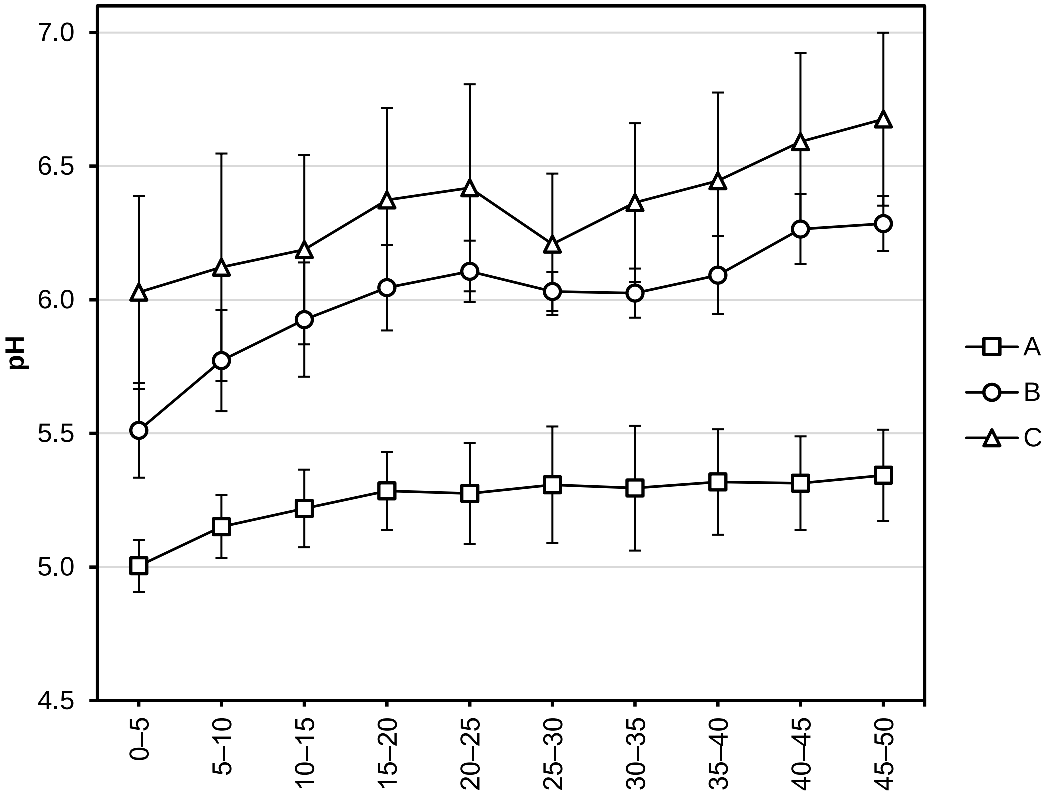


Figure 9 The soil pH in three hydrologic zones in Bueng Lahan, (A) the intermittently flooded zone, (B) the saturated zone, and (C) the permanently flooded zone

In Nong Waeng Non-hunting Area, the soil pH from three hydrologic zones fluctuated among soil depths. However, they tended to increase with depth (Figure 10). The soil pH of the intermittently flooded zone ranged from 6.5 to 7.9 (slightly acid – moderately acid). In a saturated zone, soil pH ranged from 6.1 to 7.6 (slightly acid – slightly alkaline). Similarly, the soil pH in the permanently flooded zone ranged from 6 .4 to 7.9 (slightly acid and moderately alkaline).

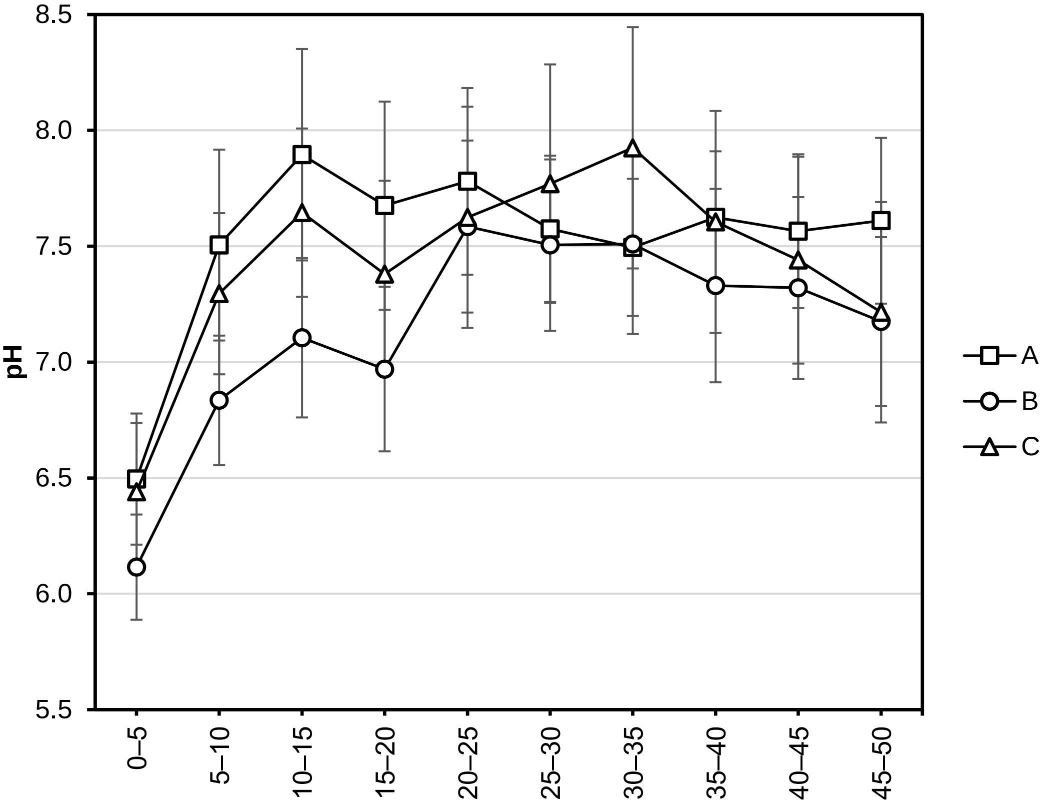


Figure 10 The soil pH in three hydrologic zones in Nong Waeng Non-hunting Area, (A) the intermittently flooded zone, (B) the saturated zone, and (C) the permanently flooded zone

In Nong Sam Muen, soil pH tended to increase with depth in both the intermittently flooded zone and the permanently flooded zone. However, the soil pH obtained from the saturated zone tended to be constant through the soil profile, with pH of 4.8 (very strongly acid). In the permanently flooded zone, soil pH ranged between 5.1 and 7.3 (strong acid – neutral). In the permanently flooded zone, the soil pH ranged from 5.2 to 7.0 (strong acid – neutral). Further, the soil pH increased dramatically from 5.5 to 7.0 in a depth of 35 – 45 cm and dropped to 6.5 in a depth of 45 – 50 cm (Figure 11).

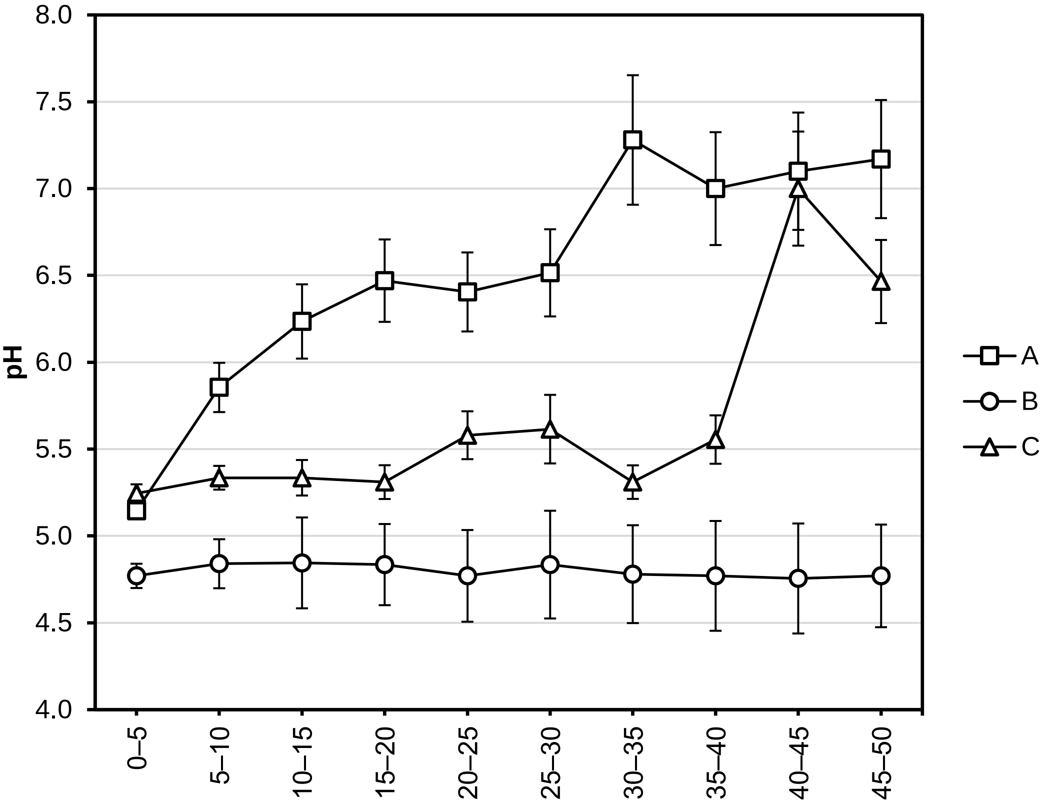


Figure 11 The soil pH in three hydrologic schemes in Nong Sam Muen, (A) the intermittently flooded zone, (B) saturated zone, and (C) permanently flooded zone

In Kaeng Lawa, the saturated zone had the lower soil pH than did other hydrologic zones (Figure 12). The soil pH ranged from 5.0 to 6.7 (very strong acid – neutral) in the intermittently flooded zone. The soil pH in the saturated zone ranged from 4.4 to 5.1 (extremely acid – strongly acid). In the permanently flooded zone, the soil pH ranged from 6.4 to 7.2 (slightly acid – neutral). In the intermittently flooded zone, the soil pH was lower at a depth of 0 – 5 cm. the pH fluctuated between the depth of 5 – 10 cm and 15 – 20 cm depth. After that, it decreased constantly with depth. Similarly, the soil pH in a saturated zone decreased with depth, but the pH at depth of 30 – 35 cm increased dramatically then declined gradually. The soil pH in the permanently flooded zone also had the same trend.

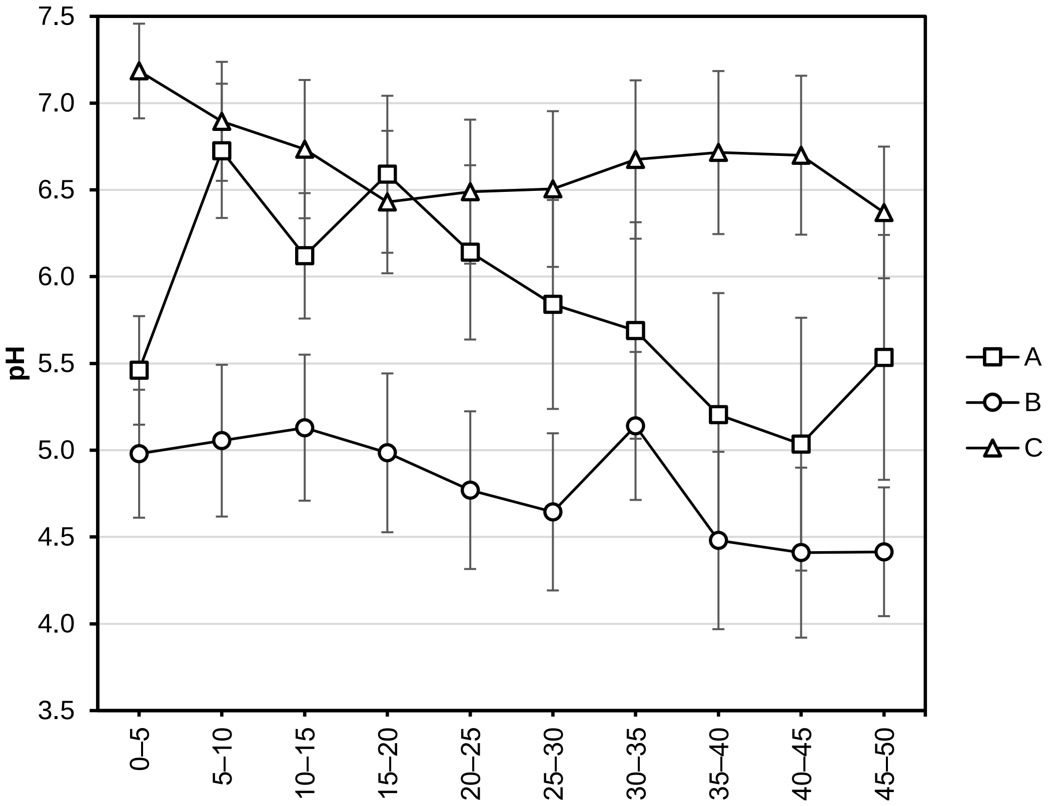


Figure 12 The soil pH in three hydrologic zones in Kaeng Lawa, (A) the intermittently flooded zone, (B) the saturated zone, and (C) the permanently flooded zone

In Huai Suea Ten, the soil pH decreased with depth, which was similar in three hydrologic zones (Figure 13). In the intermittently flooding zone, the soil pH ranged from 4.5 to 5.2 (very strongly acid – strong acid). The soil pH in the saturated zone was slightly different among depth intervals, with the range of pH 4.5 – 4.9 (very strongly acid). Same as the saturated zone, the soil reaction throughout the soil profile of the permanently flooded zone was also very strongly acid (pH 4.6 – 4.9).

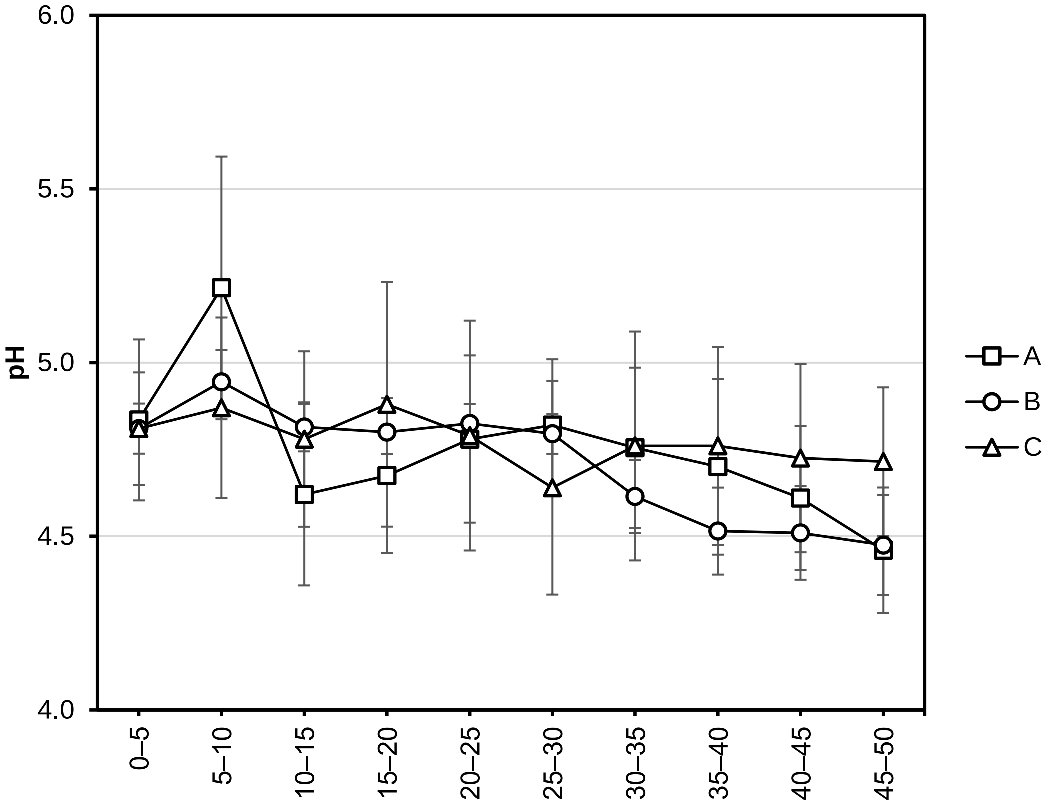


Figure 13 The soil pH in three hydrologic zones in Huai Suea Ten, (A) the intermittently flooded zone, (B) the saturated zone, and (C) the permanently flooded zone

In Nong Han Kumphawapi, soil pH did not differ among three hydrologic zones. The soil pH slightly fluctuated between 4.4 and 5.0 (Figure 14). The range of soil pH in three hydrologic zones was fallen within very strongly acid. The soil pH in the intermittently flooded zone ranged from 4.6 to 4.8, and the pH in the saturated zone ranged between 4.5 and 4.8. Soil pH ranged from 4.6 to 4.9 in the permanently flooded zone.

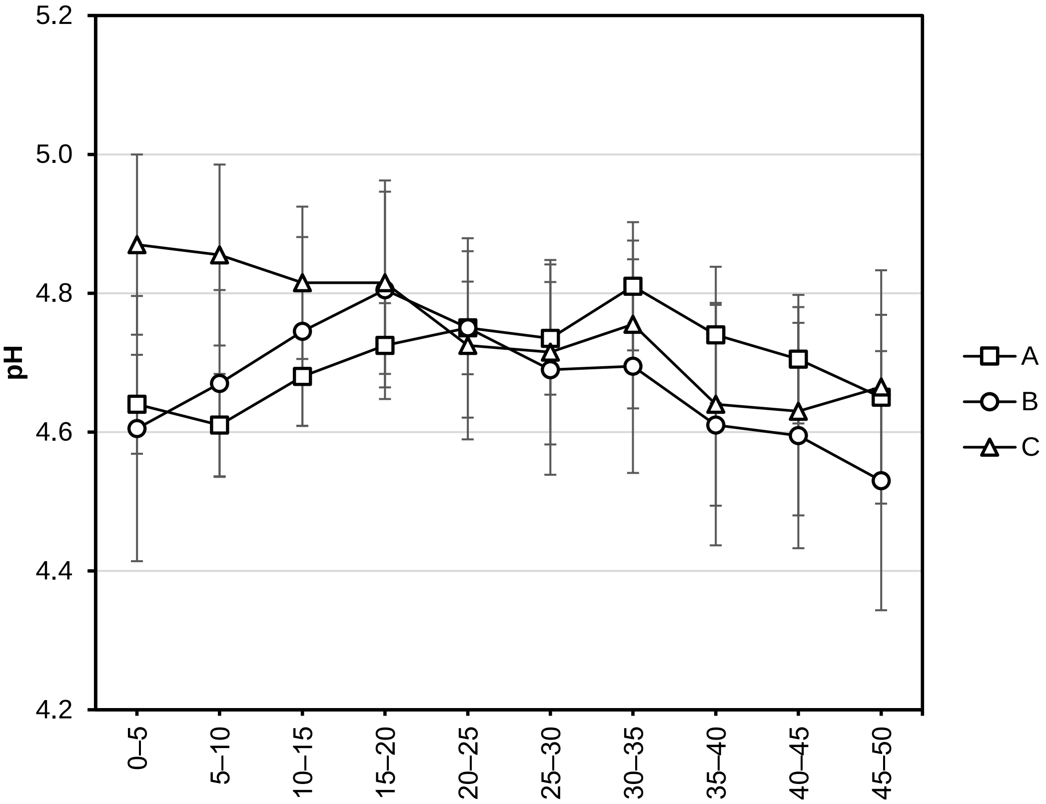


Figure 14 The soil pH in three hydrologic zones in Nong Han Kumphawapi, (A) the intermittently flooded zone, (B) the saturated zone, and (C) the permanently flooded zone

In Nong Pla Khun, soil pH obtained from three hydrologic zones increased with increasing depth (Figure 15). In the intermittently flooded zone, soil pH fluctuated among soil depth, ranging from 4.6 to 4.9 (very strongly acid). However, soil pH tended to increase with soil depth in both the saturated and permanently flooded zone. The soil reaction in saturated zone ranged from 4.7 to 5.0 (very strongly acid) while the permanently flooded zone ranged between 4.7 and 5.2 (strongly acid – strong acid).

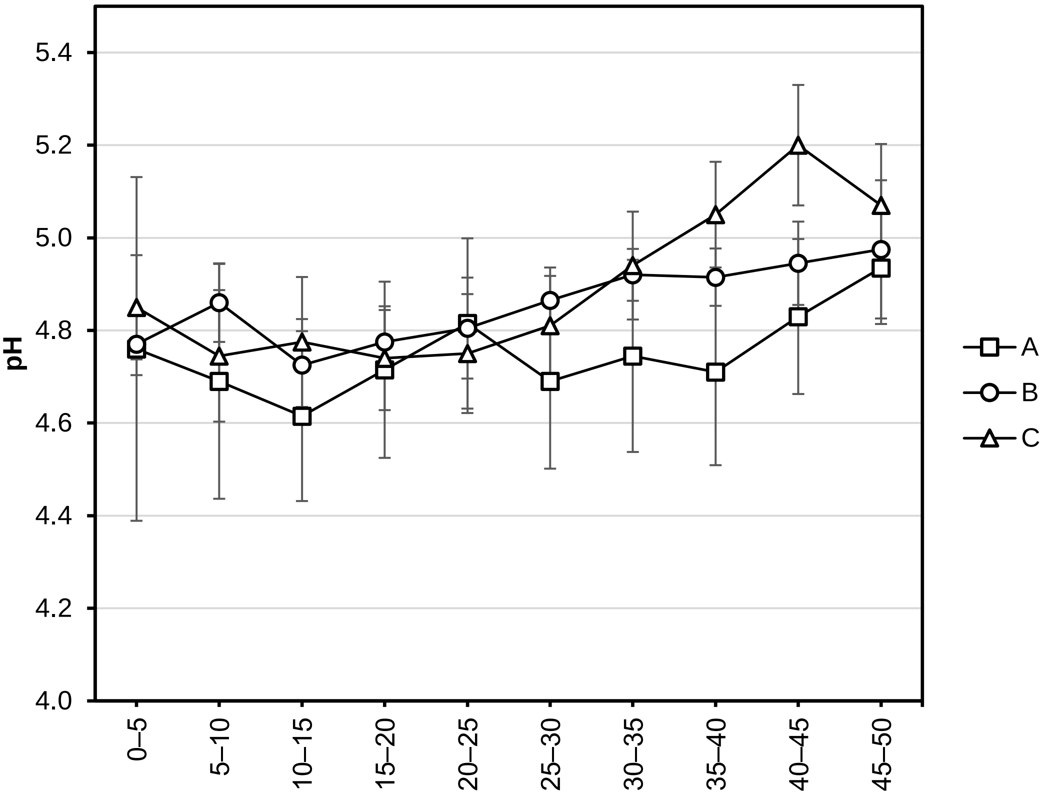


Figure 15 The soil pH in three hydrologic zones in Nong Pla Khun, (A) the intermittently flooded zone, (B) the saturated zone, and (C) the permanently flooded zone

In Bueng Kluea, soil pH fluctuated among soil depth (Figure 16). The trend of soil pH in both the intermittently flooding and saturated zone fall within the range of 5.0 – 5.5 while the soil pH of the permanently flooded zone fluctuated near pH 5. The soil pH in the intermittently flooded zone ranged from 5.1 to 5.4 (strong acid). The soil reaction in the saturated zone ranged from 5.0 to 5.4 (strong acid), whereas soil reaction in the permanently flooded zone ranged between 4.9 and 5.1 (very strongly acid – strong acid).

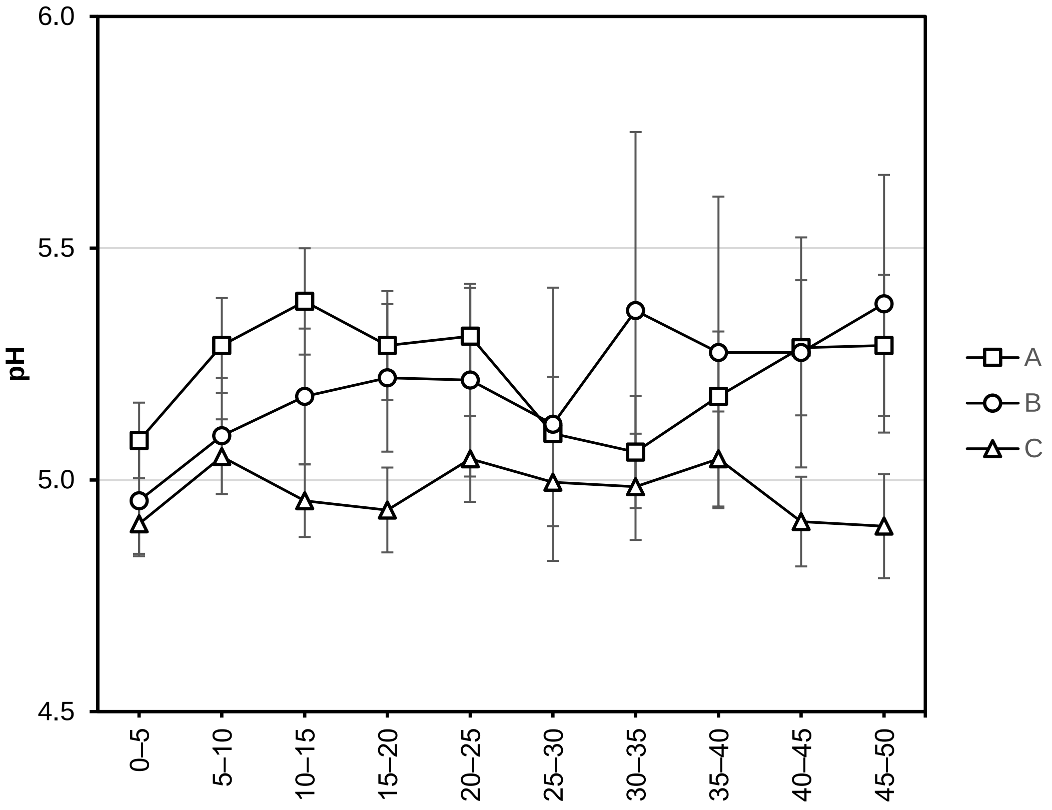


Figure 16 The soil pH in three hydrologic schemes in Bueng Kluea, (A) the intermittently flooded zone, (B) the saturated zone, and (C) the permanently flooded zone

In Sop Mun-Chi, the soil pH in three hydrologic zones slightly fluctuated among soil depth. In the intermittently flooded zone, the soil pH constantly increased with soil depth, ranging from 5.0 to 5.3 (very strong acid – strong acid). In the saturated zone, soil pH ranged between 5.0 and 5.1 (very strong acid – strong acid). The soil pH was stable (pH 5.0) at a depth of 0 – 30 cm, then slightly increased to 5.1 and remained until reached a depth of 0 – 50 cm. In the permanently flooded zone, the soil pH fluctuated from 5.2 to 5.4, which fall within strong acid (Figure 17).

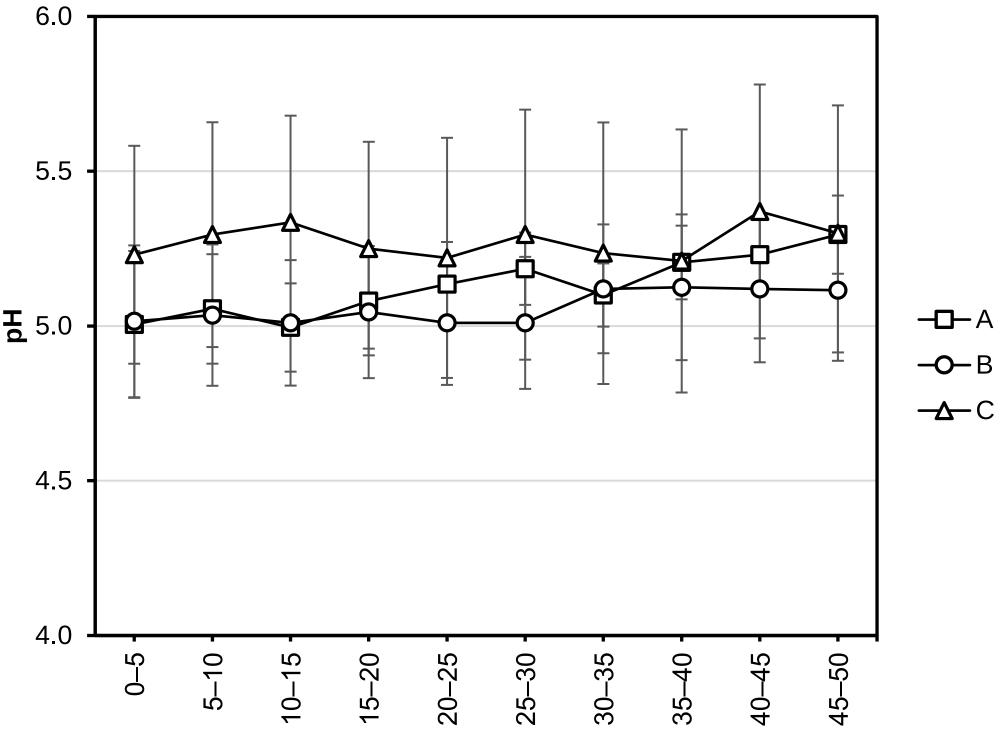


Figure 17 The soil pH in three hydrologic zones in Sop Mun-Chi, (A) the intermittently flooded zone, (B) the saturated zone, and (C) the permanently flooded zone

4.1.5 Profiles of soil organic carbon

In Bueng Lahan, soil organic carbon (SOC) concentration decreased with depth in three soil profiles (Figure 18). Every depth of the intermittently flooded zone contained higher SOC concentration than did all depths of both saturated and permanently flooded zone. These had almost similar SOC concentration at the lower 25 cm. However, the upper 25 cm of the two zones was different. In the permanently flooding zone, the abnormal peak of soil organic carbon was observed at a depth of 15 – 20 cm. Among three hydrologic zones, the average SOC concentration of each soil profile was significantly different ($P < 0.01$). The intermittently flooded zone had the highest soil organic carbon concentration (19.95±2.70 g C kg^{-1}, $P < 0.05$) than do other soil profiles. The soil organic carbon concentration did not significantly differ between the saturated zone and permanently flooded zone (11.63±1.15 and 10.01±2.02 g C kg^{-1}, respectively).

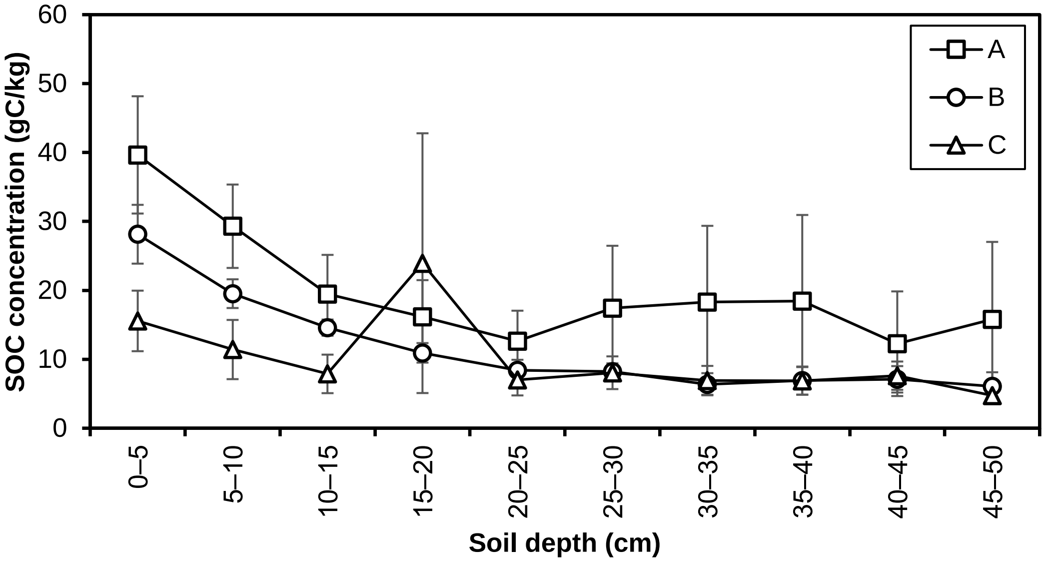


Figure 18 The soil organic carbon (SOC, Mean±S.E.) distribution throughout 0 – 50 cm depth in the soil profile of three hydrologic zones of Bueng Lahan; A = the intermittently flooded zone, B = the saturated zone, and C = the permanently flooded zone.

In Nong Waeng Non-hunting Area, the soil profiles from three hydrologic zones show a decrease of SOC concentration with depth. Three soil profiles had a different amount of soil organic carbon at the upper soil layer. The soil organic carbon of three profiles gradually decreases and reached a similar concentration at a depth of 30 – 35 cm. As a result, the SOC concentration was different among soil depth (*P* < 0.01). At least a couple of soil depth had a significant difference in soil organic carbon. The SOC concentration in the topsoil (0 – 5 cm) was significantly highest, while the lowest soil organic carbon concentration was observed in the depth of 25 – 30, 35 – 40, 40 – 45, and 45 – 50 cm. The average of SOC concentration of each soil profile was significantly different (*P* < 0.01). The intermittently flooded zone had the highest soil organic carbon concentration (6.26±0.69 g C kg^{-1}). The soil organic carbon concentration did not significantly differ between the saturated zone and permanently flooded zone (4.41±0.42 and 4.10±0.45 g C kg^{-1}, respectively).

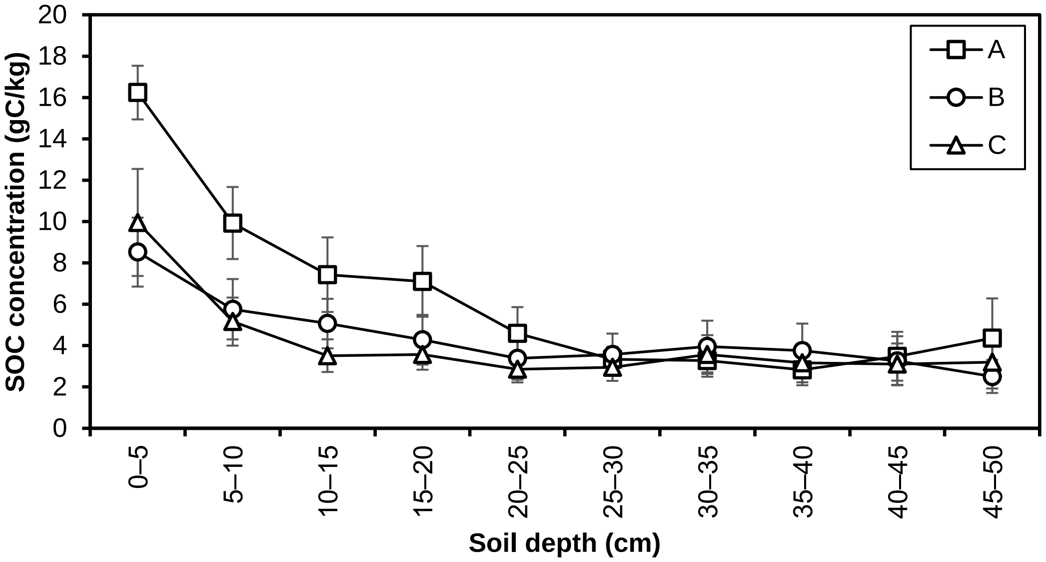


Figure 19 The soil organic carbon (SOC, Mean±S.E.) distribution throughout 0 – 50 cm depth in the soil profile of three hydrologic zones of Nong Waeng Non-hunting Area; A = the intermittently flooded zone, B = the saturated zone, and C = the permanently flooded zone.

In Nong Sam Muen, the SOC concentration from three hydrologic zones decreased with depth. Three soil profiles almost reached at the similar soil organic carbon concentration at the depth of 15 – 30 cm. However, the intermittently flooded zone had a markedly decrease with depth of soil organic carbon concentration. The soil organic carbon distribution between the saturated zone and the permanently flooded zone were similar, but they had the different values of soil organic carbon (Figure 20). The average of SOC concentration in the saturated zone (12.14±0.68 g C kg^{-1}) was higher than that of other hydrologic schemes ($P < 0.05$), followed by the soil organic carbon from the intermittently flooded zone (11.94±1.17 g C kg^{-1}). The intermittently flooded zone had the lowest average of soil organic carbon concentration (9.45±0.47 g C kg^{-1}).

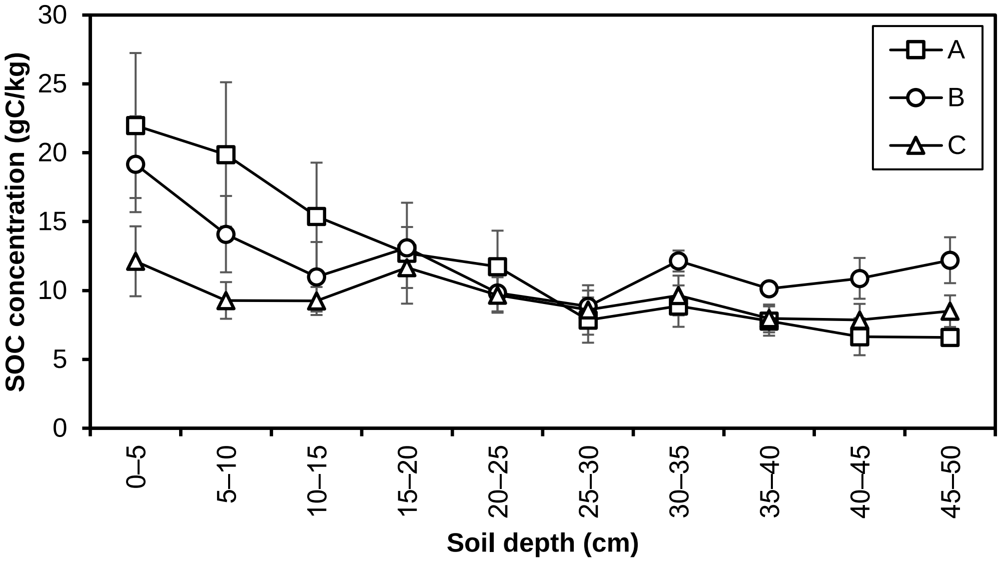


Figure 20 The soil organic carbon (SOC, Mean±S.E.) distribution throughout 0 – 50 cm depth in the soil profile of three hydrologic zones of Nong Sam Muen; A = the intermittently flooded zone, B = the saturated zone, and C = the permanently flooded zone.

In Kaeng Lawa, the average of soil organic carbon concentration in depth intervals tended to be constant throughout soil profiles (Figure 21). The average soil organic carbon concentration ranged from 3.77 to 7.68 g C kg^{-1} in the intermittently flooded zone, 4.90 and 35.36 g C kg^{-1} in the saturated zone, and 3.18 to 5.46 g C kg^{-1} in the permanently flooded zone. At a depth of 0 – 5 cm, soil organic carbon concentration were five-times more than the lowest layers (45 – 50 cm). Among the three hydrologic schemes, the average of soil organic carbon concentration at a depth of 0 – 50 cm was significantly different ($P < 0.001$), with an average of 15.37±1.31 g C kg^{-1} in the intermittently flooded zone, 11.52±0.55 g C kg^{-1} in the saturated zone, and 8.84±0.56 g C kg^{-1} in the permanently flooded zone.

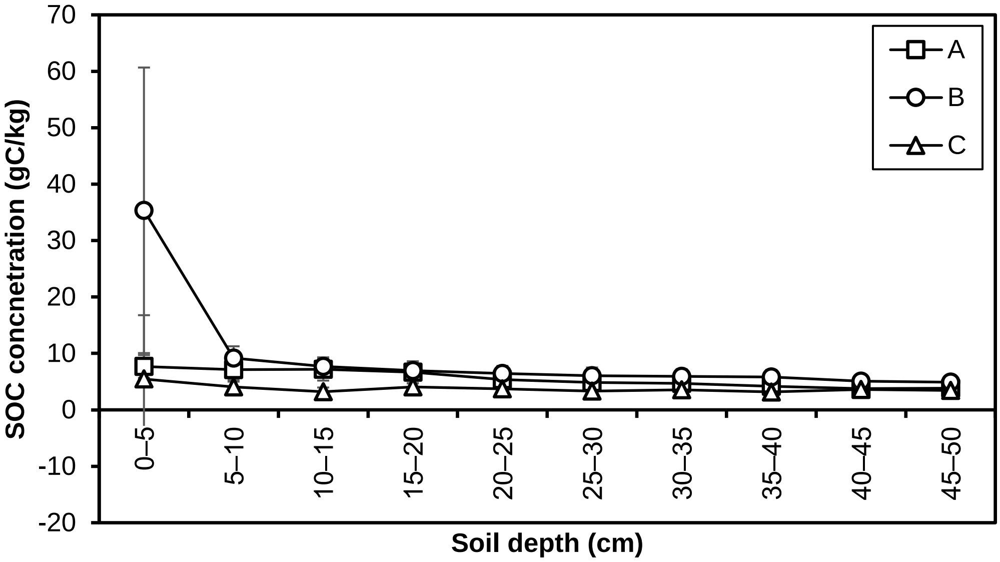


Figure 21 The soil organic carbon (SOC, Mean±S.E.) distribution throughout 0 − 50 cm depth in the soil profile of three hydrologic zones of Kaeng Lawa; A = the intermittently flooded zone, B = the saturated zone, and C = the permanently flooded zone.

In Nonghan Kumphawapi, the soil organic carbon concentration in the intermittently flooded zone and the permanently flooded zone tended to decrease with soil depth, whereas which of the saturated zone fluctuated throughout a soil profile (Figure 22). soil organic carbon concentration ranged from 36.65 and 73.77 g C kg^{-1} in the intermittently flooded zone, 29.18 to 20.77 g C kg^{-1}, and 24.29 to 30.53 g C kg^{-1} in the permanently flooded zone. The average of soil organic carbon concentration among three hydrologic zones was significantly different (P < 0.001). The intermittently flooded zone had the highest soil organic carbon concentration (56.42±5.99 g C kg^{-1}), followed by the permanently (28.58±5.99 g C kg^{-1}). The saturated zone had the lowest soil organic carbon concentration (24.96±5.99 g C kg^{-1}). However, soil organic carbon concentration did not significantly differ between the saturated zone and the permanently flooded zone.

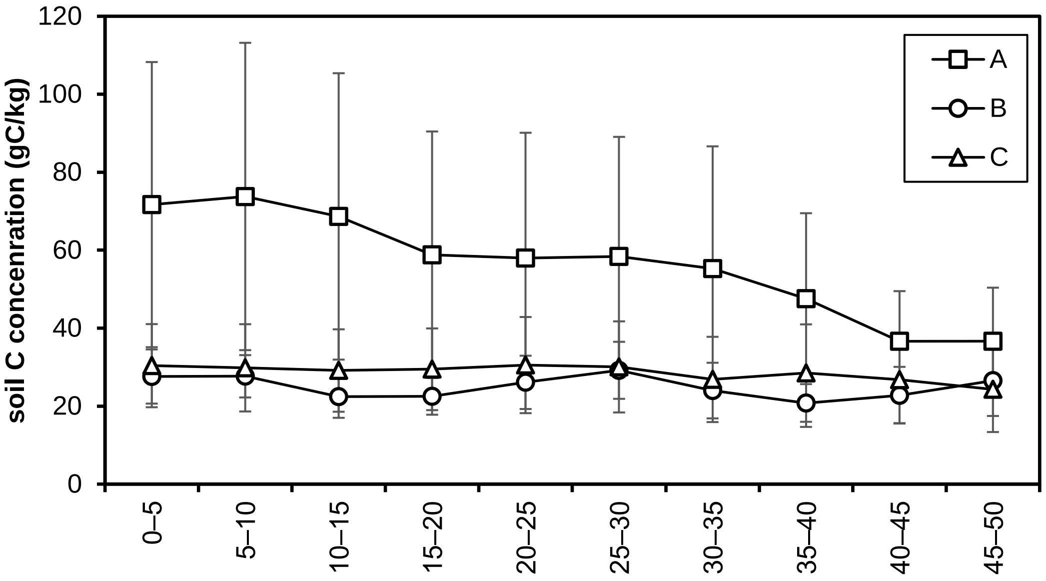


Figure 22 The soil organic carbon (SOC, Mean±S.E.) distribution throughout 0 – 50 cm depth in the soil profile of three hydrologic zones of Nong Han Kumphawapi; A = the intermittently flooded zone, B = the saturated zone, and C = the permanently flooded zone.

In Huai Suea Ten, the SOC concentration displayed a decrease with depth. The profile obtained from both the intermittently flooded zone and the saturated zone were higher soil organic carbon than that of the permanently flooded zone. However, SOC concentration was variable in the amount at the topsoil and then reached at similar values at the lowest soil depth (Figure 23). The average SOC concentration of soil profiles was not significantly different among hydrologic schemes ($P < 0.05$). However, the intermittently flooded zone held the highest SOC while the permanently flooded zone contained the lowest SOC. The average SOC concentration was 14.94±3.08 g C kg^{-1} in the intermittently flooded zone, 14.64±1.91 g C kg^{-1} in the saturated zone, and 8.32±0.64 g C kg^{-1} in the permanently flooded zone.

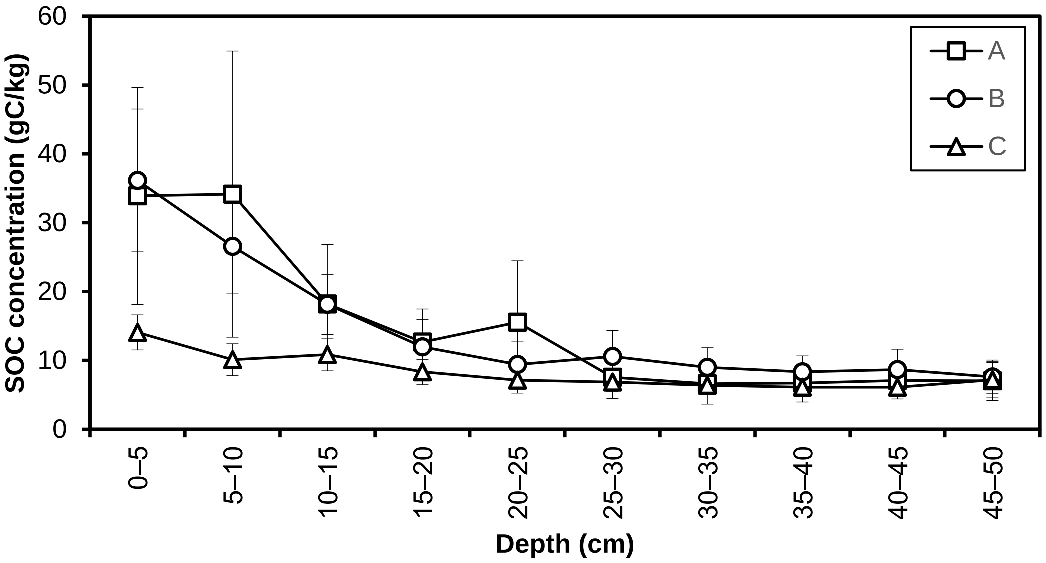


Figure 23 The soil organic carbon (SOC, Mean±S.E.) distribution throughout 0−50 cm in the soil profile of three hydrologic zones of Huai Suea Ten; A = the intermittently flooded zone, B = the saturated zone, and C = the permanently flooded zone.

In Nong Pla Khun, the average SOC concentration showed a decrease with soil depths. Further, the SOC in the top 0 – 5 cm was significantly highest SOC concentration. However, other soil depths did not significantly differ among them. The soil profile of both the intermittently flooding and saturated zone showed higher SOC in soil depth than did those of the permanently flooded zone. Average SOC at 0 – 50 cm depth was different among three hydrologic schemes. Both the intermittently flooding and saturated zone had significantly higher SOC than the permanently flooded zone ($P < 0.001$). The average SOC was 7.41±0.78 g C kg^{-1} in the intermittently flooded zone, 6.94±0.51 g C kg^{-1} in the saturated flooding zone, and 4.13±0.26 g C kg^{-1} in the permanently flooded zone.

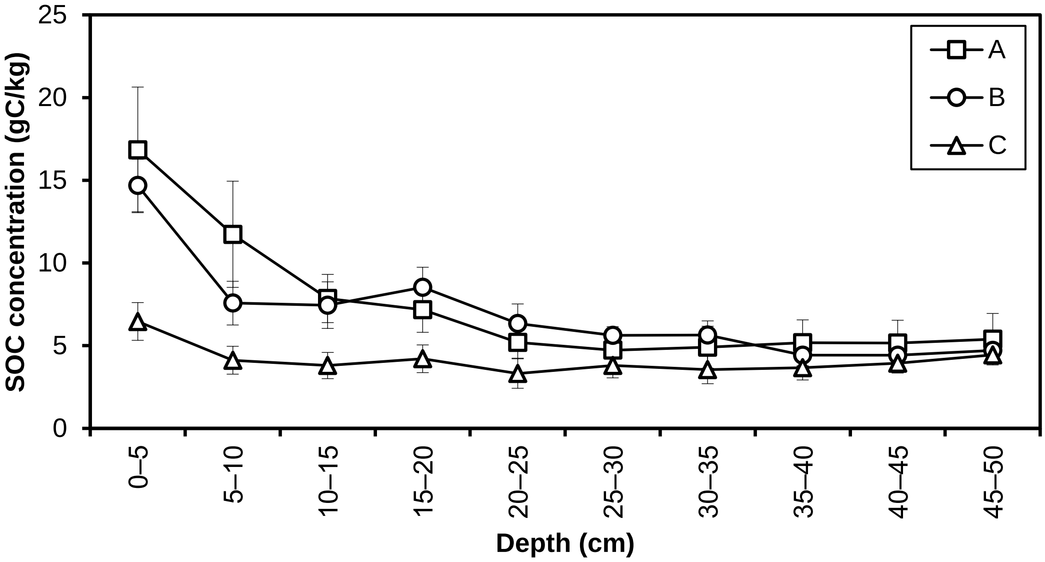


Figure 24 The soil organic carbon (SOC, Mean±S.E.) distribution throughout 0 – 50 cm depth in the soil profile of three hydrologic zones of Nong Pla Khun; A = the intermittently flooded zone, B = the saturated zone, and C = the permanently flooded zone.

In Bueng Kluea, the average SOC concentration in soil depths tended to increase with depth (Figure 25). Average SOC in every soil depth obtained from the intermittently flooded zone was higher than the permanently flooded zone. The intermittently flooded zone contained the highest SOC while the lowest was measured from the permanently flooded zone. The average SOC at 0 – 50 cm was 6.01 ± 0.53 g C kg^{-1} in the intermittently flooded zone, 7.16±0.53 g C kg^{-1}, and 5.05±0.44 g C kg^{-1}. However, the average SOC from the intermittently flooded zone did not differ significantly.

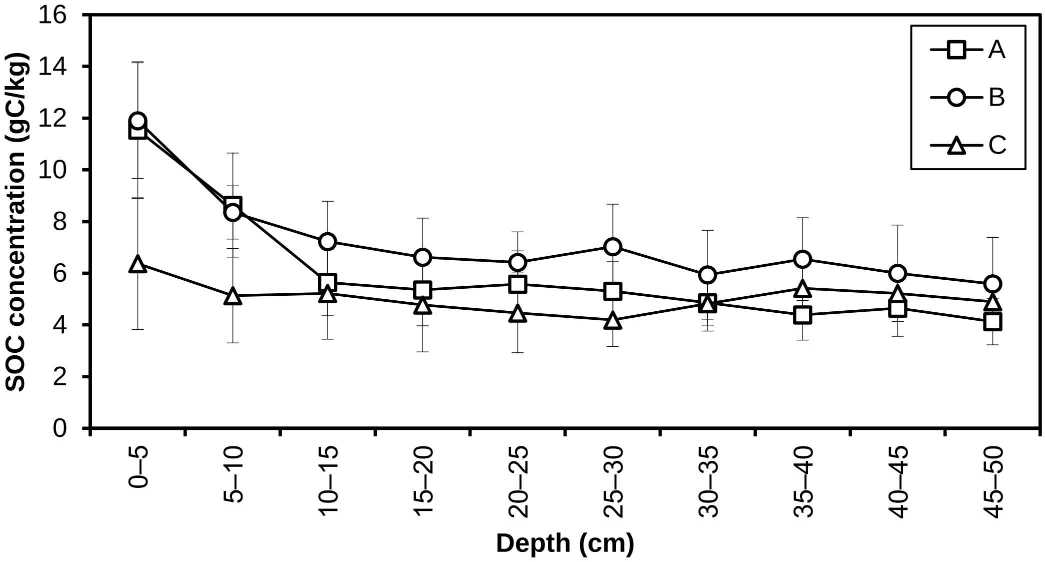


Figure 25 The soil organic carbon (SOC, Mean±S.E.) distribution throughout 0 − 50 cm depth in the soil profile of three hydrologic zones of Bueng Kluea; A = the intermittently flooded zone, B = the saturated zone, and C = the permanently flooded zone.

In Sop Mun-Chi, the SOC concentration tended to increase with depth (Figure 26). However, the average of SOC concentration did not significantly differ among soil depths ($P > 0.05$). In the intermittently flooded zone, the SOC concentration within soil profile ranged from 3.57 to 22.88 g C kg^{-1}. In the saturated zone, the SOC concentration ranged between 6.40 and 26.30 g C kg^{-1}, and the peak of average SOC concentration was observed at a depth of 10 – 15 cm. In the permanently flooded zone, the soil organic carbon ranged from 4.31 to 8.94 g C kg^{-1}. The average SOC concentration at 0 – 50 cm depth did not significantly differ among the three hydrologic zones ($P < 0.05$). However, the average SOC concentration measured from the saturated zone was highest (12.47±1.40 g C kg^{-1}), followed by which obtained from the intermittently flooded zone (9.73±1.58 g C kg^{-1}). The average SOC concentration obtained from the permanently was lowest (6.13±0.82 g C kg^{-1}).

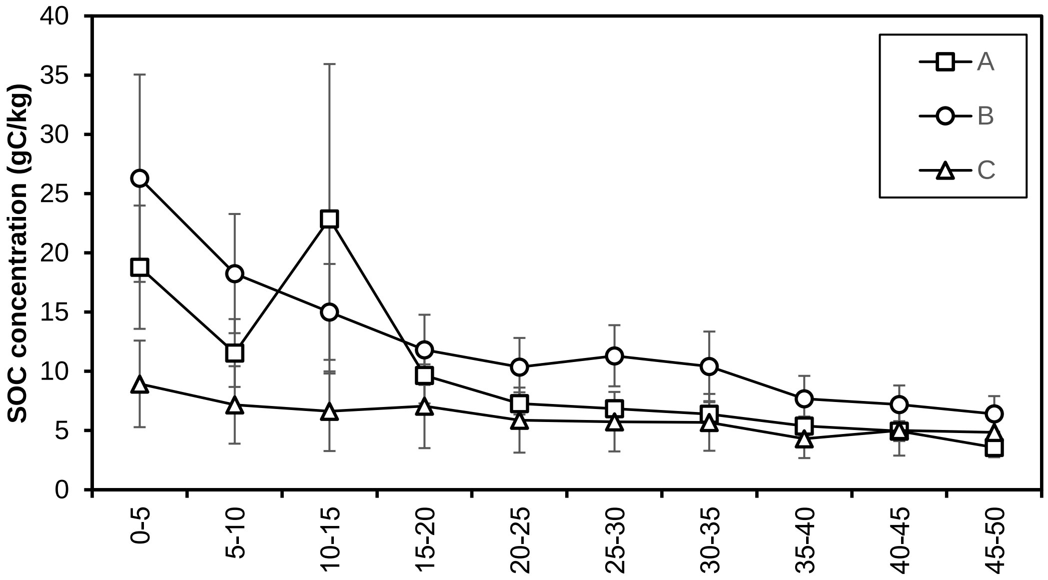


Figure 26 The soil organic carbon (SOC, Mean±S.E.) distribution throughout 0 – 50 cm depth in the soil profile of three hydrologic zones of Sop Mun-Chi; A = the intermittently flooded zone, B = the saturated zone, and C = the permanently flooded zone.

4.1.6 Soil organic carbon in different wetlands

The studied wetlands had different abilities to accumulate soil organic carbon (Table 36). At a depth of 0 – 50 cm, Nonghan Kumphawapi contained 3 – 9 times more soil organic carbon than did other wetlands, with an average of 36.69±10.35 g C kg^{-1}. Nong Waeng Non-hunting Area had the lowest soil organic carbon, with an average of 4.92±0.65 g C kg^{-1}.

In perspective of the important levels according to Ramsar criteria, both of internationally important wetlands (Nonghan Kumphawapi and Bueng Lahan) showed higher soil organic carbon concentration than do the nationally important ones. Even significant differences in soil organic carbon were not found among the nationally important wetlands, some wetlands also showed high soil organic carbon at a depth of 0 – 50 cm such as Huai Suea Ten (12.63±2.63 g C kg^{-1}), Nong Sam Muen (11.18±0.94 g C kg^{-1}), and Sop Mun-Chi (9.44±1.54 g C kg^{-1}).

Among the similar soil depth, the SOC concentration of Nonghan Kumphawapi was markedly higher than those of other studied wetlands. However, the SOC concentration in 5 cm depth of some wetlands (such as Bueng Lahan, Nong Sam Muen, Kaeng Lawa, and Sop Mun-Chi) also was higher than other wetlands (Table 36). From a depth of 10 – 15 cm to 45 – 50 cm, the SOC concentration did not significantly differ among 8 wetlands (excepting Nonghan Kumphawpi). However, soil organic carbon of those was slightly different within similar depth.

Along vertical distribution, SOC concentration was higher in the upper levels than the deeper ones. Each wetland site showed a similar pattern of soil organic carbon distribution, a decrease of soil organic carbon with depth. The analysis of 2-ways ANOVA revealed that there were significant differences in soil organic carbon among soil depths within the same wetland (Table 37). The soil organic carbon in the upper soil layers was 1.5 – 3.9 times higher than that of the lower ones, with significant difference ($P < 0.05$). However, a significant difference of soil organic carbon was not found in a profile of Nonghan Kumphawapi.

Table 36 Average SOC concentration (Mean±S.E., N = 15) in each soil depth of six studied wetlands.

Depth	Soil organic carbon concentration (g C kg^{-1})								
(cm)	LH	NW	SM	LW	ST	HK	PK	BK	MC
0 – 5	27.79 ± 4.17^{ab}	11.57 ± 1.37^{b}	17.76 ± 2.37^{ab}	16.17 ± 8.66^{ab}	28.03 ± 6.44^{ab}	43.22 ± 13.11^{a}	12.66 ± 1.78^{b}	9.94 ± 1.49^{b}	18.01 ± 3.84^{ab}
5 – 10	20.08 ± 3.08^{ab}	6.95 ± 0.97^{b}	14.42 ± 2.20^{b}	6.78 ± 1.08^{b}	23.61 ± 7.29^{ab}	43.75 ± 13.96^{a}	7.81 ± 1.38^{b}	7.37 ± 1.00^{b}	12.32 ± 2.39^{b}
10 – 15	13.97 ± 2.36^{b}	5.34 ± 0.83^{b}	11.87 ± 1.62^{b}	6.04 ± 0.99^{b}	15.72 ± 3.21^{b}	40.08 ± 13.10^{a}	6.37 ± 0.83^{b}	6.03 ± 0.86^{b}	14.84 ± 4.69^{b}
15 – 20	17.01 ± 6.23^{b}	4.99 ± 0.80^{b}	12.49 ± 1.32^{b}	5.89 ± 0.87^{b}	10.99 ± 2.06^{b}	36.94 ± 11.20^{a}	6.64 ± 0.78^{b}	5.58 ± 0.87^{b}	9.51 ± 1.68^{b}
20 – 25	9.36 ± 1.72^{b}	3.61 ± 0.58^{b}	10.41 ± 1.02^{b}	5.19 ± 0.84^{b}	10.70 ± 3.14^{b}	38.19 ± 11.47^{a}	4.96 ± 0.64^{b}	5.49 ± 0.75^{b}	7.84 ± 1.28^{b}
25 – 30	11.23 ± 3.14^{b}	3.29 ± 0.42^{b}	8.43 ± 0.84^{b}	4.74 ± 0.75^{b}	8.33 ± 1.62^{b}	39.20 ± 11.00^{a}	4.72 ± 0.47^{b}	5.51 ± 0.76^{b}	7.97 ± 1.30^{b}
30 – 35	10.55 ± 3.80^{b}	3.60 ± 0.55^{b}	10.22 ± 0.78^{b}	4.72 ± 0.64^{b}	7.34 ± 1.37^{b}	35.36 ± 11.14^{a}	4.71 ± 0.59^{b}	5.21 ± 0.69^{b}	7.50 ± 1.33^{b}
35 – 40	10.74 ± 4.21^{b}	3.25 ± 0.56^{b}	8.63 ± 0.54^{b}	4.39 ± 0.60^{b}	7.05 ± 1.16^{b}	32.27 ± 8.56^{a}	4.42 ± 0.55^{b}	5.45 ± 0.72^{b}	5.79 ± 0.90^{b}
40 – 45	8.99 ± 2.57^{b}	3.28 ± 0.60^{b}	8.46 ± 0.86^{b}	4.15 ± 0.51^{b}	7.28 ± 1.29^{b}	28.75 ± 5.91^{a}	4.51 ± 0.50^{b}	5.29 ± 0.74^{b}	5.72 ± 0.91^{b}
45 – 50	8.87 ± 3.78^{b}	3.35 ± 0.78^{b}	9.10 ± 0.90^{b}	4.07 ± 0.44^{b}	7.27 ± 1.40^{b}	29.17 ± 6.27^{a}	4.85 ± 0.56^{b}	4.87 ± 0.70^{b}	4.94 ± 0.86^{b}
0 – 50	$\mathbf{13.86\pm2.70^{b}}$	$\mathbf{4.92\pm0.65^{b}}$	$\mathbf{11.18 \pm 0.94^{b}}$	$\mathbf{6.21 \pm 1.30^{b}}$	$\mathbf{12.63 \pm 2.63^{b}}$	$\mathbf{36.69\pm10.35^{a}}$	$\mathbf{6.16\pm0.70^{b}}$	$\mathbf{6.07\pm0.78^{b}}$	$\mathbf{9.44\pm1.54^{b}}$

Remarks: Different letters in the same row indicates significant difference of soil organic carbon among wetlands (α = 0.05).

LH = Bueng Lahan, NW = Nong Waeng Non-hunting Area, SM = Nong Sam Muen, LW = Kaeng Lawa, ST = Huai Suea Ten, HK = Nonghan Kumphawapi, PK = Nong Pla Khun, BK = Bueng Kluea, and MC = Sop Mun-Chi

Table 37 Two-way ANOVA for SOC concentration in six freshwater wetlands, with three hydrologic schemes and soil depth as main fixed factors.

Sources of variation	**d.f.**	**Wetland sites**								
		LH	**NW**	**SM**	**LW**	**ST**	**HK**	**PK**	**BK**	**MC**
Hydrologic zone (A)	2	7.10**	8.38***	4.24*	14.23***	3.57*	8.33***	16.78***	4.64*	6.74**
Depth (B)	9	2.82**	12.84***	5.26***	5.82***	4.32***	0.24 NS	10.36***	2.86**	3.69***
A x B	18	0.53 NS	1.33 NS	1.29 NS	0.79 NS	0.59 NS	0.14 NS	1.68 NS	0.45 NS	0.77 NS
MS residual	120	200.29	8.12	26.39	340.69	196.05	1792.54	9.39	12.05	75.23
MS total	150	417.82	39.20	159.93	498.94	390.60	3035.07	55.33	49.98	179.77

The *F*-ratio is indicated for each variable.

NS; not sig.

* $P < 0.05$

** $P < 0.01$

*** $P < 0.001$

Remarks: LH = Bueng Lahan, NW = Nong Waeng Non-hunting Area, SM = Nong Sam Muen, LW = Kaeng Lawa, ST = Huai Suea Ten, HK = Nonghan Kumphawapi, PK = Nong Pla Khun, BK = Bueng Kluea, and MC = Sop Mun-Chi

Two-way ANOVA analysis revealed that there were the significant differences in soil organic carbon among hydrologic zones in every studied wetland (Table 37). This indicated that hydrologic conditions influence the accumulation of soil organic carbon in wetland soils. As shown in Figure 27, the average SOC concentration at 0 – 50 cm depth was significantly different among three hydrologic zones within a wetland. Although some wetland sites did not have a significant difference among hydrologic schemes, the average also differed in the value of SOC concentration among schemes. The average SOC concentration was higher SOC concentration in both the intermittently flooded zone and the saturated zone while the lowest SOC concentration was generally found in the permanently flooded zone. The intermittently flooded zone showed higher SOC concentration in many wetland sites (Bueng Lahan, Nong Waeng Non-hunting Area, Huai Suea Ten, Nonghan Kumphawapi, Nong Pla Khun,). However, some wetlands also had higher SOC concentration in the saturated zone (Nong Sam Muen, Kaeng Lawa, Bueng Kluea, and Sop Mun-Chi). The SOC concentration generally lowest in the permanently flooded zone in every wetland site.

Among the hydrologic zones, the average of SOC concentration at 0 – 50 cm was highest in the intermittently flooded zone whereas the SOC concentration obtained from the permanently flooded zone was the lowest (Figure 28A). In the intermittently flooded zone, there was a high degree of variability in SOC concentration (Figure 28B, C, D). The average SOC concentration ranged between 5.54 – 56.54 g C kg^{-1} among wetland sites, with an average of 15.37±3.83 g C kg^{-1}. Nong Han Kumphawapi had the highest SOC concentration while Kaeng Lawa had the lowest SOC concentration (Figure 28B). In the saturated zone, the average SOC concentration among wetland sites ranged from 4.40 – 24.96 g C kg^{-1}, with an average of 11.52±1.24 g C kg^{-1}. In this hydrologic conditions, Nong Han Kumphawapi still held the highest SOC concentration while the lowest was obtained from Nong Waeng Non-hunting Area (Figure 28C). In the permanently flooded zone, the average SOC concentration ranged between 3.78 – 28.60 g C kg^{-1}, with an average SOC concentration of 8.85±1.65 g C kg^{-1}. The average SOC in Nong Han Kumphawapi was still higher than the other wetland sites in this hydrologic conditions, and Kaeng Lawa had the lowest SOC (Figure 28D).

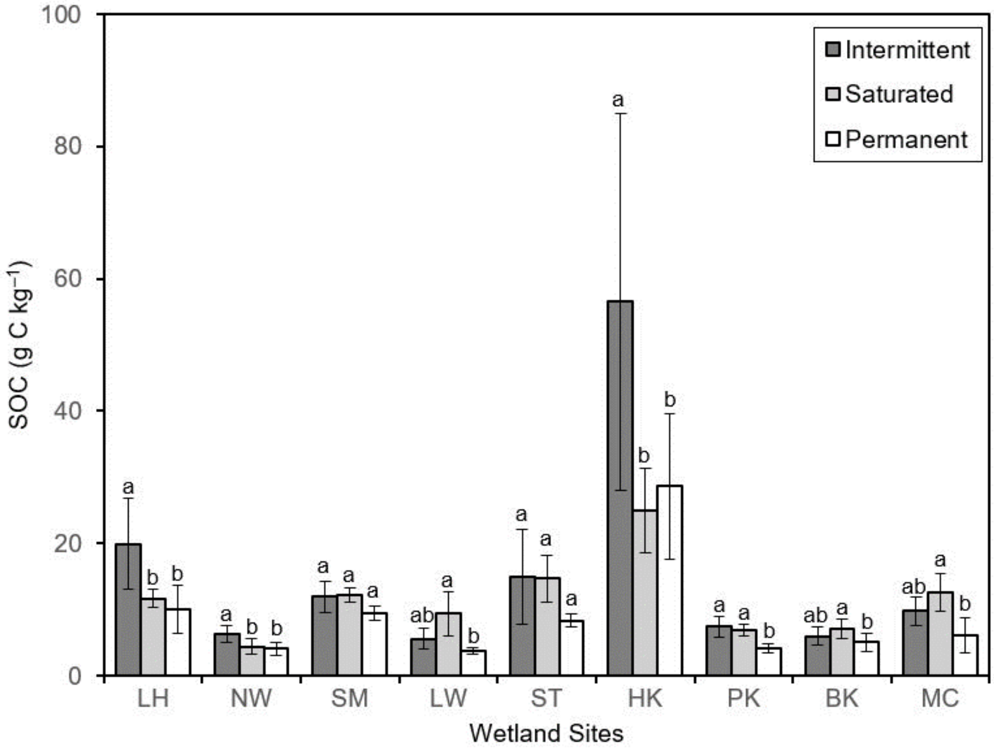


Figure 27 Distribution of SOC concentration at 0 – 50 cm depth in each wetland sites among hydrologic schemes. Different letters in the same wetland showed a significant difference among hydrologic zones ($P < 0.05$). Bars represent standard error of the mean. LH = Bueng Lahan, NW = Nong Waeng Non-hunting Area, SM = Nong Sam Muen, LW = Kaeng Lawa, ST = Huai Suea Ten, HK = Nonghan Kumphawapi, PK = Nong Pla Khun, BK = Bueng Kluea, MC = Sop Mun-Chi

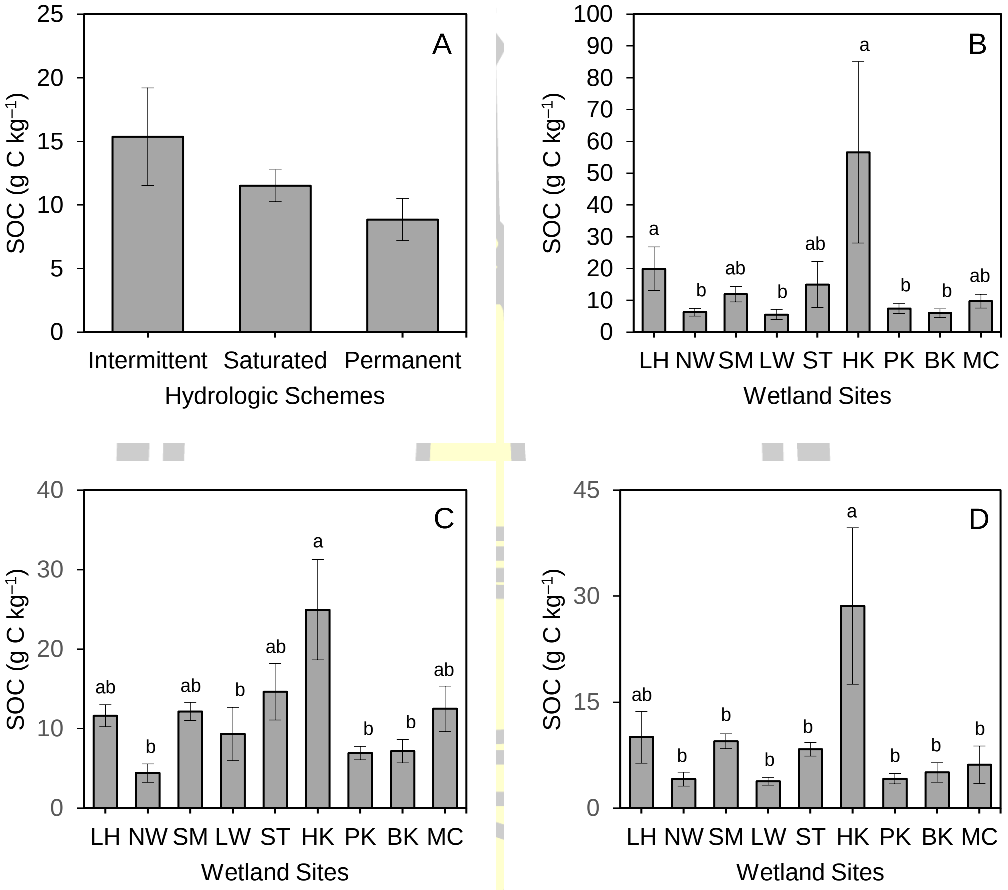


Figure 28 Mean of SOC concentration at 0 – 50 cm among wetlands within each of hydrologic zones; (A) Mean of SOC combined from all wetlands among three hydrologic schemes, (B) Mean of SOC among wetland sites within the intermittently flooded zone, (C) Mean of SOC among wetland sites within the saturated zone, and (D) Mean of SOC among wetland sites within the permanently flooded zone. Different letters show significant differences in soil organic carbon among wetlands ($P < 0.05$).

4.1.7 Soil organic carbon pools

The mean of soil organic carbon (SOC) pool at 0 – 50 cm depth of all wetlands did not significantly differ among hydrologic zones. However, the size of the SOC pool was slightly different among hydrologic zones. An average of SOC pools in the intermittently flooded zone (85.14±13.53 Mg C ha^{-1}) was highest while the permanently flooded zone (68.33±18.92 Mg C ha^{-1}) was lowest. A significant difference of SOC pools among hydrologic zones was not found in any wetlands. However, the SOC pools were also different in size among hydrologic schemes (Table 38). Both intermittently flooded zone and saturated zone had a higher soil carbon storage than did the permanently flooded zone. The highest soil carbon storage in the intermittently flooded zone was found in five wetlands; Bueng Lahan, Nong Waeng Non-hunting Area, Nong Sam Muen, Nong Pla Khun, and Bueng Kluea. Also, the highest storage of soil organic carbon in the saturated zone was found in the three wetlands; Kaeng Lawa, Huai Suea Ten, and Sop Mun-Chi. However, the storage soil organic carbon in the permanently flooded zone was also found in Nonghan Kumphawapi.

In the intermittently flooded zone, average SOC pools ranged from 38 – 142 Mg C ha^{-1}, with an average of 77.38 Mg C ha^{-1}. As shown in Table 38, the largest carbon pool was found in Bueng Lahan while the lowest carbon pool was Kaeng Lawa. Both Nong Sam Muen and Huai Suea Ten also had a large carbon pool. In the saturated zone, Nonghan Kumphawapi showed the largest SOC pool in this hydrologic condition, followed by Huai Suea Ten and Sop Mun-Chi. The smallest SOC pool was found in both Bueng Kluea and Nong Waeng Non-hunting Area. In the permanently flooded zone, the SOC pools range from 38 – 213 Mg C ha^{-1}, with an average of 68.33±18.92 Mg C ha^{-1}. In this hydrologic condition, Nonghan Kumphawapi showed an exceptionally highest SOC pool with 213.03±82.87 Mg C ha^{-1} while the lowest SOC pool was found in Nong Pla Khun.

The size of the total SOC pool at 0 – 50 cm of the wetlands in Chi River Basin ranged from 123.39 to 429.43 Mg C ha^{-1} (Table 38), with a mean of 230.85±34.84 Mg C ha^{-1}. As shown in Table 21, Nonghan Kumphawapi (429.43 Mg C ha^{-1}) was significantly highest C pool whereas Bueng Kluea (123.39 Mg C ha^{-1}) the was smallest SOC pool. The SOC pool of Nonghan Kumphawapi was 1.3 – 3.4 folds greater than others SOC pools. Other wetlands also had a greater SOC pool such as Huai Suea Ten (332.85 Mg C ha^{-1}), Bueng Lahan (291.29 Mg C ha^{-1}), Nong Sam Muen (224.35 Mg C ha^{-1}), and Sop Mun-Chi (218.45 Mg C ha^{-1}). For the internationally important wetlands, Nonghan Kumphawapi was the largest SOC pool on the Chi River Basin while Bueng Lahan had a smaller SOC pool than did some wetlands of the nationally important wetlands. Many nationally important wetlands showed the larger SOC pool, indicating that these wetlands had the ability to accumulate soil organic carbon and can be important carbon sinks of the nation.

As shown in the previous section, the soil organic carbon tended to decrease with increasing depth (Figure 18, Figure 19, Figure 20, Figure 21, Figure 22, Figure 23, Figure 24, Figure 25, and Figure 26). The SOC concentration was generally higher in the upper levels than the lower ones. As a result, much of soil organic carbon was accumulated in the upper soil. As shown in Figure 29, more than 50% of the total SOC pool of each soil profile in each wetland was stored in the upper 25 cm. In the intermittently flooded zone, the proportion of SOC that was stored in upper 25 cm ranged from 56 – 75% among wetland sites whereas the deeper 25 cm contained about 24 – 43% of the total SOC pools (Figure 29A). In the saturated zone in each wetland site, more than half of the total SOC pool were contained the upper 25 cm. The percentage of SOC pool in the upper 25 cm depth of wetlands ranged from 47 – 68% of total SOC pool while the deeper 25 cm in this hydrologic zone ranged from 31 – 52% (Figure 29B). In the permanently flooded zone, the proportion of SOC pool in the upper 25 cm ranged between 50 – 65% while the deeper 25 cm ranged from 35 – 50% of total C pool (Figure 29C). When we combine all hydrologic schemes together, the upper 25 cm depth showed a higher SOC pool than did the lower 25 cm.

Table 38 The soil organic carbon pool (Mean ± S.E.) at a depth of 0 – 50 cm among hydrologic zones of studied wetlands

Wetlands	**SOC Pools (Mg C ha^{-1})**			**Total SOC pool**
	Intermittent	**Saturated**	**Permanent**	
HK	63.81±32.19^{a}	152.59±39.14^{a}	213.03±82.87^{a}	**429.43**
LH	142.02±50.90^{a}	81.51±10.04^{ab}	67.77±25.03^{b}	**291.29**
ST	114.55±54.64^{a}	135.94±33.53^{ab}	82.37±9.53^{ab}	**332.85**
SM	103.77±21.00^{a}	81.35±7.21^{ab}	59.23±6.52^{b}	**244.35**
MC	70.12±15.81^{a}	102.98±23.55^{ab}	45.36±19.50^{b}	**218.45**
NW	57.29±11.80^{a}	38.50±10.08^{b}	37.99±9.18^{b}	**133.78**
LW	38.86±10.89^{a}	86.31±28.54^{ab}	35.96±5.07^{b}	**161.14**
PK	62.50±13.06^{a}	49.07±5.92^{b}	31.44±5.55^{b}	**143.01**
BK	43.54±9.66^{a}	38.02±7.42^{b}	41.82±11.18^{b}	**123.39**
Mean	**77.38±11.63^{a}**	**85.14±13.53^{a}**	**68.33±18.92^{a}**	**230.85±34.84**

Remarks: The different lowercase in the same rows shows the significant difference of soil organic carbon pool among hydrologic zones ($P < 0.05$).

HK = Nonghan Kumphawapi, LH = Bueng Lahan, ST = Huai Suea Ten, SM = Nong Sam Muen, MC = Sop Mun-Chi, NW = Nongwaeng Non-hunting Area, LW = Kaeng Lawa, PK = Nong Pla Khun, and BK = Bueng Kluea

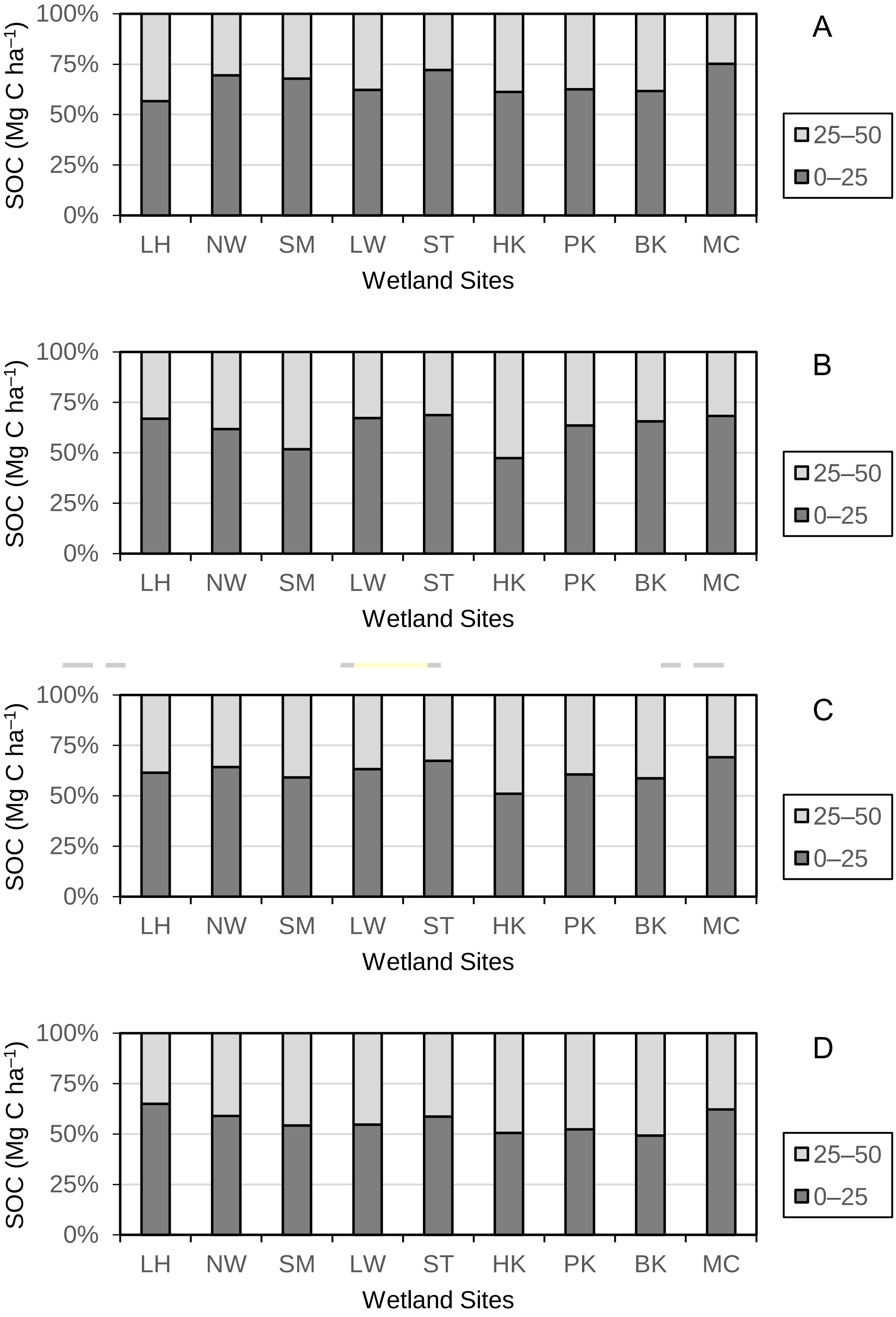


Figure 29 Distribution of SOC pools between the upper 0 – 25 cm and 25 – 50 cm in; (A) the intermittently flooded zone, (B) the saturated zone, (C) the permanently flooded zone, and (D) All hydrologic schemes. HK = Nonghan Kumphawapi, LH = Bueng Lahan, ST = Huai Suea Ten, SM = Nong Sam Muen, MC = Sop Mun-Chi, NW = Nongwaeng Non-hunting Area, LW = Kaeng Lawa, PK = Nong Pla Khun, and BK = Bueng Kluea

4.2 Discussions

4.2.1 Characteristics of studied wetlands

The study of soil properties and plant coverages suggested that the wetlands in this study can be identified to freshwater marshes. The dominated vegetation in the wetlands was the graminoid and herbaceous group. Generally, wetland soils can be classified into 2 types—mineral and organic soils. The wetland soils in this study were mineral soil because the percentage of organic carbon was less than 12 – 20 % (Mitsch and Gosselink 2015). Soil textures in these wetlands comprised mainly of coarse particles (silt and sand). Such textures had variability on wetland site, but coarse textures (texture comprise of a high content of sand particle) were frequently found in many wetlands. Thus, soils in sampling areas were mineral soils because wetland soil consisted of a high content of sand particles (Table 13, Table 14, Table 15, Table 16, Table 17, Table 18, Table 19, Table 20, and Table 21). It might be that accumulation of soil particle could be possibly affected by flooding every year. The coarse particles flowing from the main river were deposited after the flood season had gone. As a result, coarse particles were mostly dominated in the upper soils, especially in both intermittently flooded zone and saturated zone of many wetlands (Table 13, Table 14, Table 15, Table 16, Table 17, Table 18, Table 19, Table 20, and Table 21), where covered by vegetation. The deposited sediment could be a result of soil erosion and siltation during flood season from the main river (Office of Environmental Policy and Planning 2000). The coarse sediments could be trapped by these vegetations. As a result, these areas can play as a sink for the sediments (Walalite et al. 2016).

The soil bulk density varied among wetland sites (Table 22). The lowest bulk density in the intermittently flooded zone of Nonghan Kumphawapi (0.23 g cm^{-3}) suggested that the soils might be organic soils because bulk density of this soils type generally ranged from ~0.02 to 0.35 g cm^{-3} (Vepraskas and Craft 2016). Further, other properties (colors; shown in Supp. Table 6, clay texture, and more organic matters) also confirmed the properties of organic soils. For other wetlands, the wetland soils were mineral because their bulk density ranged between 1.0 and 2.0 g cm^{-3} (Mitsch and Gosselink 2015). Although soil bulk densities were different among wetland sites, most of them fall between 1 – 2 g cm^{-3}, suggesting that soil structure was quite similar among wetland sites.

In this study, the wetlands consisted of many genera such as *Typha* spp., *Panicum* spp., *Eleocharis* spp., *Polygonum* spp., *Cyperus* spp., and other species of grasses and sedge. These species are frequently found in freshwater marshes around the world (Mitsch and Gosselink 2015). For this reason, wetlands in this study, therefore, identified to freshwater marshes. A higher number of species and family in the saturated zone than those of the intermittently flooded zone suggested that diversity of the saturated zone would be higher than the intermittently flooded zone.

According to filed observations, all wetland sites had a presence of invasive species especially *Mimosa pigra* L., *Eichhornia crassipes* (Mart.) Solms, and *Salvinia cucullata* Roxb. ex Bory. This suggested that the wetlands were highly disturbed by invader species. The invasive species can change wetlands into monotype vegetation, which lead to changing in habitat structure, lower biodiversity in both number and quality. As a result, nutrient cycling and productivity, as well as the food web, will be altered, and then will change the capacity of soil carbon accumulation in wetland ecosystems in the future (Zedler and Kercher 2004).

The soil pH of wetlands in this study varied widely from acidity to alkalinity. The pattern of changes in soil pH in hydrologic schemes differed among wetland sites (Figure 9, Figure 10, Figure 11, Figure 12, Figure 13, Figure 14, Figure 15, Figure 16, and Figure 17). Soil pH in the wetlands falls between 5.0 – 7.5 in many sites. This follows from the fact that marsh soils, freshwater sediments, and flooded soil should have the pH ranges of 5.0 – 7.0, 6.0 – 7.0, and 6.5 – 7.5, respectively. These pH ranges are generally found in wetland ecosystems (Reddy and DeLaune 2008). Further, soil pH tends to higher in soils subjected to longer flooding time (Redman and Pratrick 1965). However, the soil pH higher than 7.0 in some wetland such as Nong Waeng Non-hunting Area (Figure 10) and Kaeng Lawa (Figure 12) could be result of saline soil effect (Gupta and Abrol 1990). Further, salt-affected soils are found in two wetland areas.

4.2.2 Distribution of soil organic carbon in freshwater wetlands

In wetland ecosystems, the primary productivity is always more than the rate of decomposition of plant litters. As a result, the remains of organic matters wetlands are buried and accumulated in wetland soils, which subjected to anaerobic conditions. In this study, the accumulation of soil organic matter had the same trend in the soil profile of all wetlands. All soil profile displayed a decrease of soil organic carbon with depth. This suggested that there were sustained accumulation of organic carbon in wetlands system (Bernal and Mitsch 2008). However, this could be indicated that the decomposition rates were higher than the accumulation. For this reason, the organic matter accumulated in studied wetlands were primarily derived from herbaceous vegetation, which dominate in these areas. Reddy and DeLaune (2008) revealed that plant litters from herbaceous vegetations are poor in lignin and recalcitrant components, compared to woody plant tissues that comprise primarily of complex tissues. Thus, the plant litter derived from herbaceous vegetation, therefore, were highly degradable, and they cannot be accumulated in deep profiles. As a result, little soil organic carbon was therefore stored in the lower depth. The decrease SOC with depth in soil profiles was typically found in temperate and tropical wetlands (Becker-Heidmann and Scharpenseel 1992; Bernal and Mitsch 2012) and also found in many upland soils, and mineral soils in floodplains (Jobbágy and Jackson 2000; Ricker and Lockaby 2015).

Although similar trends of vertical distribution were generally found all wetlands, soil organic carbon fluctuated among soil depth in some wetland sites (Figure 18, Figure 26). Soil organic carbon showed abnormal peaks in the 15 – 20 cm in the soil profile of Bueng Lahan, as well as the 10 – 15 cm in the soil profile of Sop Mun-Chi. This is probably due to the remains of manure from the cattle, which cause high concentration in soil organic carbon concentration. For another reason, it likely to be undecomposed organic matter and plant remnants resulting in high content of soil organic carbon in these depths. As shown in Figure 21, soil profile in Kaeng Lawa shown an almost constant soil organic carbon concentration with depth. This possibly suggested that very little soil organic carbon is being stored in the soils (Bernal and Mitsch 2008).

4.2.3 Difference of soil organic carbon within wetland and Chi River Basin

In general, accumulation of organic matter in wetlands are governed by hydrology, which controls primary productivity, decomposition rate, flows of organic matter as well as sedimentation of dissolved organic matter (Qualls and Richardson 2003; Mitsch and Gosselink 2015). In the studied wetland, soil organic carbon was either high in the intermittently flooding or saturated zone. This could be due to more plant coverages in these areas, which contribute to highly productive organic matters. The productivity of the plants is generally associated with soil organic carbon in freshwater wetlands (Brinson et al. 1981). High net primary productivity or biomass could result in high carbon accumulation stocks (Adame et al. 2013). Thus, more productivity in both intermittently flooded zone and saturated zone can be in turn provide more soil organic carbon accumulation in these hydrologic conditions.

The hydrologic pulsing effect could be the result of high productivity in the two zones because net productivity and high density of vegetation are always found in the edge of wetland (Odum 1969; Odum et al. 1995), where both zones are located. In the permanently flooded zone, few submerged species were found in this area. The permanent flood could limit production of vegetation. On the other hands, the finding in this study differed from a previous study. Bernal and Mitsch (2013b) revealed that the soil organic carbon was higher in the open water area (same as the permanently flooding area in this study) than both the edge and emergent area (same as the intermittently flooded zone and the saturated zone, respectively). They suggested that more carbon accumulation in the open water was a result of the effect of permanently anaerobic condition that provides a slow decomposition of soil organic carbon in this area.

The SOC concentration was obviously lowest in the permanently flooded zone of all wetlands. According to the field observation, the lower of soil organic concentration might probably be caused by net productivity of vegetation as described previously. The observations indicated that the permanent flooding areas were rarely covered by some submerged species such as *Hydrilla verticillata* (L. f.) Royle and *Utricularia aurea* Lour. in the permanent flooding zone, while other hydrologic schemes were dominated and completely covered by the emergent macrophytes. Gopal and Masing (1990) suggested that a net aboveground primary productivity of submerged macrophytes in freshwater marshes are much lower than of which emergent macrophytes. Thus, according to field observation, it could be inferred that lower soil organic carbon in the submerged areas could be due to less plant productivity (Bauer and Black 1994).

On the other hand, the sediments deposited can possibly support the fact that high SOC in both intermittently flooding and saturated zone. Walalite et al. (2018) revealed that soil organic matter had been exported from floodplain to river floodplain, but plant coverages, such as bamboo and grass, can trap sediments. As a result, the sediments were trapped in this zone and provide more soil organic carbon accumulation. Further, Mulholland and Kuenzler (1979) described that the export of soil organic carbon is generally higher in wetlands that open to the river than the upland watershed. This complies the fact that SOC in the permanently flooded zone was low.

The SOC concentration and SOC pools were different among wetland sites. This suggested that there was different capacity in storing soil carbon despite in the similar wetland type. It suggested that the carbon pools in wetlands were influenced by many factors. The study of plant coverages revealed there were differences of dominant vegetation among wetlands. Although most of the dominant species in each wetland were slightly different, most of them were the herbaceous group, which could be the rapidly decomposable organic matters. Therefore, some species such as *Cyperus* spp. which are fiber-rich species could provide more recalcitrant tissue, and provide long-term accumulation of organic matters in soils of some wetlands such as Nonghan Kumphawapi, Nong Sam Muen, Huai Suea Ten, and Sop Mun-Chi.

The agricultural practice surrounded wetland areas and the effect of flood season is thought to be the main driver that probably affect soil carbon storing in these wetlands. The difference in surrounding land use and degree of water regulation, resulting in the spatial difference of either autochthonous or allochthonous carbon input into the wetland system (Carnell et al. 2018). The spatial difference of soil carbon could be due to plant species composition, soil characteristics, and variation in annual hydroperiods (Cierjacks et al. 2011). All wetland in this study subjected to the floodplain area, where large quantities of sediments were deposited (Stallard 1998). Each of wetland could receive a different amount of sediment, which likely to be from different environmental conditions. The study of suspended sediments in Chi River Basin revealed that amount of sediment associated with a size of drainage area, suggesting that wetland with large areas such as Nonghan Kumphawapi, Bueng Lahan, and Sop Mun-Chi could accumulate a large amount of sediment (Hydro and Agro Informatics Institute 2012). As a result, these areas, therefore, has the potential to accumulate organic carbon from sediment after flooding season (Zehetner et al. 2009). The study of soil texture indicating that wetland, where soil organic carbon was high, tended to accumulate fine sediments such as clay and silts. However, field observations also suggested that large quantities of organic matter were present in the soil profile of wetland where carbon was high (Bueng Lahan, Nong Sam Muen, Huai Suea Ten, Nonghan Kumphawapi, and Sop Mun-Chi). The soils in these wetlands always have a dark color (Supp. Table 1, Supp. Table 3, Supp. Table 5, Supp. Table 6, and Supp. Table 9), which suggested that they contained much of soil organic matters in the soil profiles.

4.2.5 Comparison of soil organic carbon

There were differences of SOC pool among wetland sites. The differences did not conform to the level of importance according to an inventory of wetlands of international and national importance in Thailand. However, one of the internationally important wetlands (Nonghan Kumphawapi) showed the largest size of the SOC pool, which highlights the importance of this wetland as carbon sinks of the Chi River Basin. Bueng Lahan also had a large SOC pool when compared with some of the nationally important wetlands such as Nong Waeng Non-hunting Area, Nong Pla Khun, and Bueng Kluea. However, many wetlands of the nationally important wetlands, including Huai Suea Ten, Nong Sam Muen, and Sop Mun-Chi, also had the ability to storing the large size of SOC pool. This suggested that the important wetlands of Chi River Basin provide not only provisioning service for people and organisms but also regulating services as the important carbon sinks of greenhouse gases in the basin-scale.

When wetlands in this study were compared with other ecosystems in Thailand, the wetlands stored higher soil organic carbon than did forest ecosystems. This suggested that wetlands in the Chi River Basin had high potential to accumulate soil carbon as much as forests do (Table 39). Soil organic carbon storage in studied wetlands was larger than those of agricultural land uses. Previously, seasonally flooded forest, which is one of the wetland types along the Chi River were also studied. The SOC pool of the forested wetlands was as much as the SOC pool in the wetland of this study. However, some of the freshwater wetlands in this study such as Nong Waeng Non-hunting Area, Bueng Kluea, Nong Pla Khun, and Kaeng Lawa had smaller SOC pool than do the forested wetland. It is likely that the marsh in this study had a lower rate of carbon sequestration than the forested wetland. It suggested that the forested wetland community provide more recalcitrant organic material than do marshes. Further, herbaceous plant dominated in marshes also produces more parenchymatic tissue that can more decompose than the counterpart from woody tissue.

When freshwater marshes in this study were compared with other wetlands in previous studied (Table 40), SOC pool in this study (230 Mg C ha^{-1}) was similar to deep freshwater marshes and shallow freshwater marsh in Australia (230 and 200 Mg C ha^{-1}, respectively) (Carnell et al. 2018). Freshwater wetlands in this study seemed to contain more soil organic carbon than two wetland types because soil carbon pool of wetland in this study was just calculated at 0 – 50 cm, which the depth interval was thinner than those in Australia. The SOC pool in this study was 1.5 – 2 time larger than SOC pool of freshwater meadow and permanent open water in Victoria, Australia. The SOC pool in mineral wetlands in Congaree National Park in the USA was slightly similar to carbon storage in wetlands of this study, where wetland soils were identified as mineral soils. However, The SOC pool in this study is 2 times smaller than those of organic wetlands in floodplain forest in USA (Ricker and Lockaby 2015). Further, the SOC pool in other floodplain landscapes (flats and levees) were more 2 times smaller than the SOC pool of this study. This comparison suggested that the freshwater wetland in this study plays an important role as soil carbon sinks similar to other wetlands around the world.

Table 39 Comparison of soil organic carbon pool among selected ecosystem in Thailand

Ecosystems	**Depth (cm)**	**Carbon Stock (Mg C ha^{-1})**	**Sources**
Freshwater wetlands	0 – 50	230	This study
Dry evergreen forest	0 – 50	118	Lichaikul et al. (2006)
Seasonally flooded forest	0 – 100	226	Gomontean (2012)
Hill evergreen + mixed deciduous forest	0 – 100	197	Pibumrung et al. (2008)
Mixed deciduous forest	0 – 100	157	Tangsinmankong et al. (2007)
Take Plantation	0 – 100	71	Tangsinmankong et al. (2007)
Reforestation[‡]	0 – 100	147	Pibumrung et al. (2008)
Plantation of Acacia	0 – 50	66	Lichaikul et al. (2006)
Corn field	0 – 50	57	Lichaikul et al. (2006)
Agriculture[†]	0 – 100	95	Pibumrung et al. (2008)
Agroforestry system	0 – 100	4	Podong and Permpool (2017)

Remarks

[†] comprise: Fallow land, Paddy field, Corn fied, and Orchard (*L. chinensis* Sonn. spp.)

[‡] comprise: *G. aborea* Roxb., *T. grandis* Linn., *P. marcrocarpus* Kurz., *A. xylocapa* (Kurz) Craib., and *A. catechu* (L.f.) Wild.

Table 40 Comparison of soil organic carbon pools (SOC pools) in wetlands from different regions.

Location	**Wetland types**	**Depths (cm)**	**Carbon Stock (Mg C ha^{-1})**	**Sources**
Chi River Basin, Thailand	Freshwater marshes	0 – 50	230	This study
Victoria, Australia	Shallow freshwater marshes	0 – 100	200	Carnell et al. (2018)
	Freshwater meadow	0 – 100	130	
	Deep freshwater marsh	0 – 100	230	
	Permanent open freshwater	0 – 100	110	
Eastern coast, Florida	Salt marshes	0 – 30	49	Doughty et al. (2016)
Congaree National Park, USA	Floodplain forest	0 – 100		Ricker and Lockaby (2015)
	– Levees		109	
	– Flats		108	
	– Mineral wetlands		193	
	– Organic wetlands		533	

CHAPTER 5
CONCLUSIONS

5.1. Conclusions

According to a result of plant coverage, the wetlands in the Chi River Basin of this study can be tentatively identified as freshwater marsh. These freshwater wetlands were mineral wetlands because most of the wetland soils in this study were less than 12 – 20% of organic carbon content. Further, wetland soils were composed mostly of the coarse particle (sand and silt), resulting in high bulk density were found in all wetlands. The coarse particle (sand and silt) always had a poorer capacity to hold particulate organic matter than clay particle. All evidence supported the fact that the wetlands in this study were mineral wetlands and freshwater marshes.

The vertical distribution of soil organic carbon in all wetland sites was similar. Soil organic carbon concentration decreased with depth, suggesting that accumulation of soil organic carbon was influenced by soils depth. Also, soil organic carbon in wetlands of the Chi River Basin had a higher rate of decomposition than the rate of accumulation. However, accumulation of soil organic carbon in the freshwater wetlands may be different because there were the differences of soil organic carbon concentration among wetland sites. High variability of soil organic carbon among wetland sites could be primarily due to both autochthonous input (biomass production within a system) and allochthonous input (organic matters and sediment from other systems).

The gradient of inundation in wetland area established the hydrologic schemes in wetlands areas (including the intermittently flooded zone, the saturated zone, and the permanently flooded zone), which influence the accumulation of organic carbon in wetland soils. Soil organic carbon concentration was different among three hydrologic zones, where governed by different plant coverages. The dense coverage of vegetation in the intermittently flooded and saturated zone provided a high amount of SOC accumulation by both trapping sediment and production of biomass. Conversely, flooding season can easier leach organic matter in the permanently flooded zone than do other hydrologic zones because there were few submerged species covered in this zone. Therefore, the amount of soil organic carbon in wetland soils was depended on the hydrologic zone of the wetland area.

Freshwater wetlands in the Chi River Basin had different size of soil organic carbon (SOC) pools. Nonghan Kumphawapi had the largest size of SOC pool while Bueng Kluea had the smallest SOC pool. Both of the internationally important wetlands (Nonghan Kumphawapi and Bueng Lahan) showed high carbon storage capacity. However, many of the nationally important wetlands also had greater SOC pool such as Nong Sam Muen, Huai Suea Ten, and Sop Mun-Chi. When the SOC pools of these wetlands were compared with other ecosystems in Thailand especially forest ecosystems, these wetlands showed larger carbon storage than some forest ecosystems and agricultural land uses. Furthermore, the carbon storage capacity of these wetlands showed was as much as the storage of freshwater wetland in other regions. This suggested that these wetlands provided the regulating service as carbon sinks in the Chi River Basin. However, they could be the biggest source of greenhouse gases at the same time. Therefore, the wetland in the Chi River Basin should be highlighted as an important carbon sink in a broader scale, such as watershed scale, national scale or a regional scale.

5.3. The implication of the study

Our study on soil organic carbon pools in the wetlands provides a further comprehensive on the status of soil carbon pools in freshwater wetlands in a watershed-scale. We desire to highlight the internationally and nationally important wetlands in the Chi River Basin in Thailand as the carbon sinks for mitigating our changing climate in the local and national scale. Also, this data will possibly be important for facilitating the estimation of the national carbon sinks and greenhouse emission in this sector. In our study, Nonghan Kumphawapi, an internationally important wetland, showed the highest potential to store soil organic carbon. This suggested that the internationally important wetlands provided, not only habitat for waterfowl according to the Ramsar criteria and deliver provisioning services for people, but also play an important role as sink of soil organic carbon. Similarly, many wetlands of the nationally important wetlands (Nong Sam Muen, Huai Suea Ten, and

Sop Mun-Chi) also had the high soil organic carbon, suggesting that they can be soil carbon sinks as important as the internationally important wetlands do. Therefore, these important wetlands should be issued as one of the important ecosystems of the nation, which could offset greenhouse gases from the atmosphere.

Furthermore, nine freshwater wetlands comprised of the areas with the difference of hydrologic zone. The difference of hydrologic zone in wetland area resulted in the different accumulation of soil carbon content which was high in both intermittently flooded and saturated zone. These areas are the transitional area between wetland and agricultural area, which were susceptible to be changed as agricultural land. This could provide drawing and planning policy to manage using of wetland areas because these zones contain a large amount of soil organic carbon. More than half of the carbon pools stored in the upper soil depth, suggesting that if soil structure of these areas is disturbed by agriculture activities, soil organic carbon will be easy to oxidize and emitted into the atmosphere. Furthermore, the upper 25 cm is the general depth for plowing in agricultural activities, which were extensive in most area of wetlands in the Chi River Basin. Therefore, the freshwater wetlands in this study can be either source or sinks of greenhouse gases, depending on practice in these areas.

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APPENDIX

Supplementary Data

Supp. Table 1 Soil profile and soil color of Bueng Lahan

Soil profile	**Depth (cm)**	**Soil color**
Sampling Station 1: 47P X 0813238 Y 1731773 	0 – 22 22 – 33 34 – 50	– 5 YR 4/4 – 7.5 YR 4/1 – 7.5 YR 2.5/1

Supp. Table 1 (continued)

Soil profile	Depth (cm)	Soil Color
Sampling Station 2: 47P X 0812520 Y 1733604 	0 – 42 43 – 50	– 7.5YR 2.5/1 – 7.5 YR 5/4

Supp. Table 1 (continued)

Soil profile	**Depth (cm)**	**Soil Color**
Sampling Station 3 47P X 0807240 Y 1728816 	0 – 5 5 – 10 10 – 40 41 – 50	– 7.5YR 3/1 – 7.5YR 4/1 – 7.5YR 2.5/1 – 7.5YR 5/3

Supp. Table 1 (continued)

Soil profile	Depth (cm)	Soil Color
Sampling Station 4: 47P X 0808914 Y 1728068 	0 – 10 10 – 50	– 7.5YR 2.5/1 – 7.5YR 4/3

Supp. Table 1 (continued)

Soil profile	Depth (cm)	Soil Color
Sampling Station 5: 47P X 0810041 Y 1725791 	0 – 15 16 – 50	– 10YR 3/1 – 10YR 6/3

Supp. Table 2 Soil profile and soil color of Nong Waeng Non-hunting Area

Soil profile	Depth (cm)	Soil Color
Sampling Station 1: 48P X 0208701 Y 1762622 	0-10 10-26 26-50	– 7.5YR 2.5/1 – 5Y 5/2 – 2.5Y 6/4

Supp. Table 2 (continued)

Soil profile	**Depth (cm)**	**Soil Color**
Sampling Station 2: 48P X 0208601 Y 1762630 	0 – 25 26 – 40 41 – 50	– 7.5YR 2.5/1 – 10YR 5/2 – 10YR 7/4

Supp. Table 2 (continued)

Soil profile	**Depth (cm)**	**Soil Color**
Sampling Station 3: 48P X 0208461 Y 1762693 	0 – 3 4 – 38 39 – 50	– 2.5YR 2.5/1 – 2.5Y 6/3 – 2.5Y 6/8

Supp. Table 2 (continued)

Soil profile	**Depth (cm)**	**Soil Color**
Sampling Station 4: 48P X 0208469 Y 1762931 	0 – 20 20 – 27 27 – 50	– 7.5YR 4/2 – GLEY1 5/5G & GLEY1 8/N – GLEY1 8/N & 5Y 7/8

Supp. Table 2 (continued)

Soil profile	**Depth (cm)**	**Soil Color**
Sampling Station 5: 48P X 0208564 Y 1763122 	0 – 5 5 – 36 36 – 50	– 2.5Y 2.5/1 – 2.5Y 7/8 – 2.5YR 8/4

Supp. Table 3 Soil profile and soil color of Nong Sam Muen

Soil profile	**Depth (cm)**	**Soil Color**
Sampling Station 1: 48Q X 0181379 Y 1815244 	0 – 30 30 – 50	– 5YR 7/2 – GLEY2 6/5PB + mottle 7.5YR 6/8 (15%)

Supp. Table 3 (continued)

Soil profile	**Depth (cm)**	**Soil Color**
Sampling Station 2: 48Q X 0181745 Y 1814736 	0 – 10 10 – 50	– GLEY2 4/1 – 2.5YR 5/8

Supp. Table 3 (continued)

Soil profile	**Depth (cm)**	**Soil Color**
Sampling Station 3: 48Q X 0183488 Y 1813907 	0 – 10 10 – 50	– GLEY1 4/10Y – 5YR 4/2

Supp. Table 3 (continued)

Soil profile	Depth (cm)	Soil Color
Sampling Station 4: 48Q X 0183544 Y 1814724 	0 – 9 10 – 40 41 – 50	– GLEY1 5/10Y – 7.5YR 7/8 – GLEY1 4/10Y

Supp. Table 3 (continued)

Soil profile	Depth (cm)	Soil Color
Sampling Station 5: 48Q X 0183172 Y 1816052 	0 – 5 6 – 50	– GLEY1 5/10Y – 5YR 6/6

Supp. Table 4 Soil profile and soil color of Kaeng Lawa

Soil profile	**Depth (cm)**	**Soil Color**
Sampling Station 1: 48Q X 2550354 Y 1783246 	0 – 13 13 – 28 28 – 50	– 10YR 4/1 – 10YR 6/3 – 7.5YR 6/4

Supp. Table 4 (continued)

Soil profile	**Depth (cm)**	**Soil Color**
Sampling Station 2: 48Q X 0250023 Y 1786584 	0 – 15 16 – 50	– GLEY1 3/10Y – 5YR 5/6

Supp. Table 4 (continued)

Soil profile	**Depth (cm)**	**Soil Color**
Sampling Station 3: 48Q X 0255004 Y 1789678 	0 – 10 11 – 50	– 5YR 4/2 – 7.5YR 5/4

Supp. Table 4 (continued)

Soil profile	Depth (cm)	Soil Color
Sampling Station 4: 48Q X 0254193 Y 1787051 	0 – 50	– 10YR 6/4

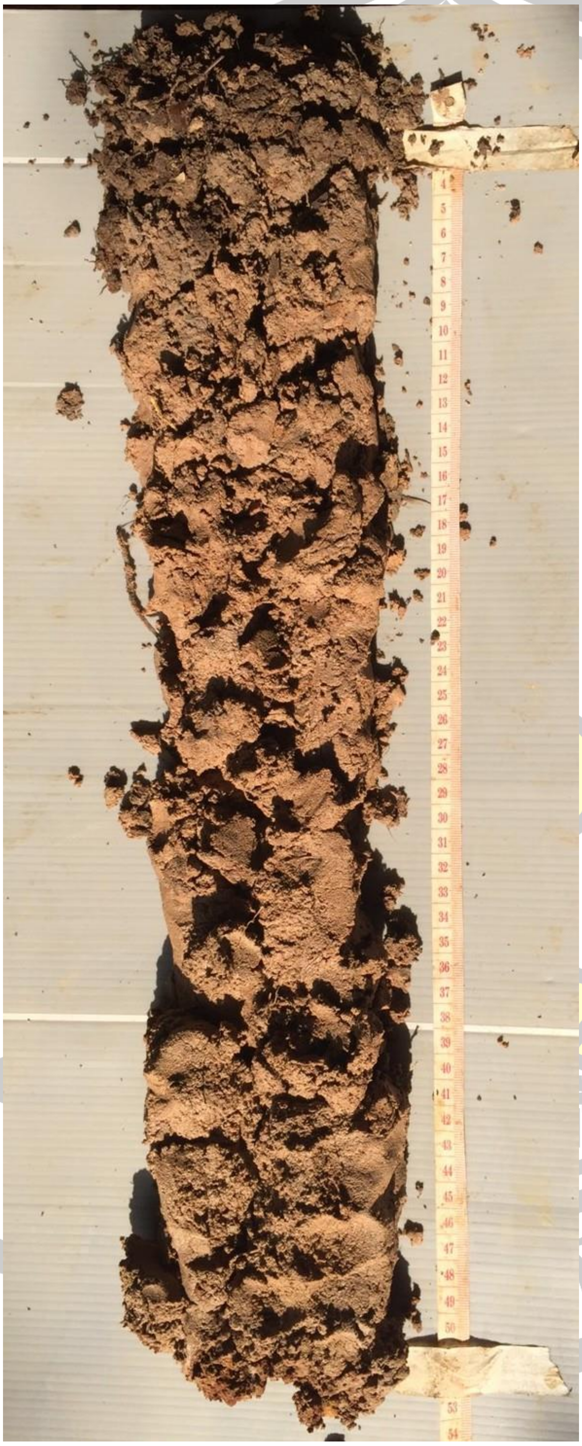
Supp. Table 4 (continued)

Soil profile	**Depth (cm)**	**Soil Color**
Sampling Station 5: 48Q X 0253111 Y 1784606 	0 – 50	– 7.5YR 7/3

Supp. Table 5 Soil profile and soil color of Huai Suea Ten

Soil profile	Depth (cm)	Soil Color
Sampling Station 1: 48Q X 0264083 Y 1855940 	0 – 18 18 – 50	– 7.5YR 4/2 – 10YR 4/1

Supp. Table 5 (continued)

Soil profile	Depth (cm)	Soil Color
Sampling Station 2: 48Q X 0262578 Y 1856643 	0 – 5 5 – 50	– 7.5YR 3/1 – 7.5YR 5/4

Supp. Table 5 (continued)

Soil profile	Depth (cm)	Soil Color
Sampling Station 3: 48Q X 0261673 Y 1856454 	0 – 5 5 – 40 40 – 50	– 7.5YR 3/2 – 7.5YR 5/3 – 2.5YR 5/1 + mottle 10YR 6/8 (5%)

Supp. Table 5 (continued)

Soil profile	Depth (cm)	Soil Color
Sampling Station 4: 48Q X 0261054 Y 1855376 	0 – 20 20 – 50	– 7.5YR 2.5/1 – 7.5YR 5/3

Supp. Table 5 (continued)

Soil profile	**Depth (cm)**	**Soil Color**
Sampling Station 5: 48Q X 0262339 Y 1852535 	0 – 25 25 – 50	– 5YR 2.5/1 – 2.5YR 4/4

Supp. Table 6 Soil profile and soil color of Nonghan Kumphawapi

Soil profile	Depth (cm)	Soil Color
Sampling Station 1: 48Q X 0289775 Y 1896582 	0 – 50	– GLEY1 1.25/N

Supp. Table 6 (continued)

Soil profile	Depth (cm)	Soil Color
Sampling Station 2: 48Q X 0288817 Y 1899806 	0 – 20 21 – 40 41 – 50	– GLEY1 3/N + 7.5YR 4/4 – GLEY1 3/N – GLEY2 2.5/5 PB

Supp. Table 6 (continued)

Soil profile	Depth (cm)	Soil Color
Sampling Station 3: 48Q X 0288601 Y 1903137 	0 – 50	– GLEY1 2.5/N

Supp. Table 6 (continued)

Soil profile	**Depth (cm)**	**Soil Color**
Sampling Station 4: 48Q X 0294484 Y 1902816 	0 – 50	– GLEY1 2.5/N

Supp. Table 6 (continued)

Soil profile	**Depth (cm)**	**Soil Color**
Sampling Station 5: 48Q X 0291624 Y 1897685 	0 – 50	– GLEY1 2.5/N

Supp. Table 7 Soil profile and soil color of Nong Pla Khun

Soil profile	**Depth (cm)**	**Soil Color**
Sampling Station 1: 48P X 0392785 Y 1765693 	0 – 20 20 – 50	– 2.5Y 4/4 – 5YR 6/8

Supp. Table 7 (continued)

Soil profile	**Depth (cm)**	**Soil Color**
Sampling Station 2: 48P X 0393142 Y 1767028	0 – 10	– GLEY1 4/1
	10 – 50	– 5YR 4/2 + mottle 10R 4/8 (1%)

Supp. Table 7 (continued)

Soil profile	**Depth (cm)**	**Soil Color**
Sampling Station 3: 48P X 0395783 Y 1768005 	0 – 50	– 7.5YR 5/1 + mottle 2.5YR 5/8 (20%)

Supp. Table 7 (continued)

Soil profile	**Depth (cm)**	**Soil Color**
Sampling Station 4: 48P X 0395340 Y 1767066 	0 – 10 10 – 26 26 – 50	– 5YR 5/1 – 7.5YR 5/3 + mottle 5YR 5/8 (30%) – 5YR 4/1 + mottle 10R 4/8 (30%)

Supp. Table 7 (continued)

Soil profile	**Depth (cm)**	**Soil Color**
Sampling Station 5: 48P X 03940008 Y 1765720 	0 – 10 10 – 50	– GLEY1 4/1 – 5YR 4/2 mottle 2.5YR 4/8 (20%)

Supp. Table 8 Soil profile and soil color of Bueng Kluea

Soil profile	Depth (cm)	Soil Color
Sampling Station 1: 48Q X 0396508 Y 1771795 	0 – 10 10 – 50	– 2.5YR 5/3 – 5YR 6/4 mottle 10R 4/8

Supp. Table 8 (continued)

Soil profile	**Depth (cm)**	**Soil Color**
Sampling Station 2: 48Q X 0313106 Y 1797205 	0 – 10 10 – 50	– 10YR 4/1 – 5YR 6/4

Supp. Table 8 (continued)

Soil profile	**Depth (cm)**	**Soil Color**
Sampling Station 3: 48Q X 0396501 Y 1774561 	0 – 6 6 – 50	– 10YR 6/3 –10YR 6/4 mottle 5YR 5/8

Supp. Table 8 (continued)

Soil profile	**Depth (cm)**	**Soil Color**
Sampling Station 4: 48Q X 0392772 Y 1774797 	0 – 10 10 – 31 31 – 50	– GLEY1 5/1 – 2.5 Y 5/3 – GLEY2 3/1

Supp. Table 8 (continued)

Soil profile	**Depth (cm)**	**Soil Color**
Sampling Station 5: 48Q X 0394263 Y 1773225 	0 – 5 5 – 22 22 – 33 33 – 50	– 10YR 5/2 – 2.5Y 6/2 – 7.5YR 5/1 – 10YR 6/8

Supp. Table 9 Soil profile and soil color of Sop Mun-Chi

Soil profile	**Depth (cm)**	**Soil Color**
Sampling Station 1: 48P X 0470481 Y 1678650 	0 – 15 16 – 40 41 – 50	– 7.5YR 6/1 – GLEY1 5/N – GLEY1 7/N

Supp. Table 9 (continued)

Soil profile	Depth (cm)	Soil Color
Sampling Station 2: 48P X 0469367 Y 1678347 	0 – 50	– 7.5YR 5/4

Supp. Table 9 (continued)

Soil profile	Depth (cm)	Soil Color
Sampling Station 3: 48P X 0469300 Y 1677313 	0 – 50	– GLEY1 3/N

Supp. Table 9 (continued)

Soil profile	Depth (cm)	Soil Color
Sampling Station 4: 48P X 0466992 Y 1677753 	0 – 50	– 7.5YR 6/2 + 2.5YR 4/6

Supp. Table 9 (continued)

Soil profile	**Depth (cm)**	**Soil Color**
Sampling Station 5: 48P X 0467065 Y 1678794 	0 –10 10 – 50	– 2.5YR 5/1 – GLEY1 5/10Y + 2.5YR 4/8

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