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Map Manipulation for Rice Soil Fertility Classification of the Mekong Delta, Vietnam

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Abstract
In Vietnam, the Mekong Delta is the most importance region for rice production. Nowadays, the crops intensification and the exploitation of the soil for rice production, which led to soil degradation. Since, it is necessary to evaluate and delineate rice soil fertility for proper use. In addition, the development of GIS technology, which makes mapping and delineating easier. The delineation soil fertility classes were conducted together with the suggestion and recommendation for proper uses depending on identified soil constraints. The collection of soil morphology, chemical and physical data analysis within the Delta. Soil map of soil of the delated was also collected for converting soil map legend classified by WRB (World Reference Based) system into soil fertility map classified by FCC system. Soil constraints for suitable uses and managements were also recommended. The study results show that Mekong Delta has 35 FCC soil fertility types. Eleven (11) soil constraints for cultivation were also identified, it is most from acid sulfate soils (ASS), and saline soils (SS); including Slightly acid (**a**$^-$), Strongly acid (a), High P fixation and high Fe toxicity potential (**i**), Low available P (**p**), Strongly actual ASS (**c**), Slightly actual ASS (**c**$^-$), Shallow potential ASS (**f)** Deep potential ASS (**f**$^-$), Slight salinity (**s**$^-$), Strongly salinity (**s**), Ability low supply mineral (**k**), Ability low nutrient retention (**e**), Low organic carbon content (**o**).

***Keywords**:* FCC, WRB, conversion, soil fertility, constraints, recommendation, Mekong delta.

1. Introduction
The Mekong delta is the largest areas for rice production in Vietnam. The intensive farming, rice cropping, unbalanced nutrients application. Besides, less application of organic fertilizers, which causing soil degradation (Guong, V.T. et al., 2010). In addition, floods prevention by several dike construction causing less accumulation of alluviall material, soil less fertilized and causing soil become more degraded (Guong, V.T. et al., 2016). The agricultural intensive cultivation that increased the pressure on soil, led to degradation and pollution of soils (Minh, V.Q. and Tri, L.Q., 2016). The Fertility Capability Soil Classification system (FCC) was developed more than 25 years ago to interpret soil taxonomy and soil tests in a quantitative manner that is relevant to growing plants (Buol et al., 1975; Sanchez et al., 1982). It is now widely used and included in the worldwide FAO soils database (FAO, 1995). Most of class limits were borrowed from Soil taxonomy (Soil Survey Staff, 1994) or the FAO/UNESCO soil classification system (FAO, 1974). Emphasis is placed on features that are easily detectable in the field, such as texture, color, depth of horizons, presence or absence of mottles, etc. Soil analytical laboratory data are only used to support the classification if available. The strength

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of this system is its ease of use, which allows the soil to be classified at several locations simply and quickly. To facilitate the easy transfer of information about soil properties and constraints, the system consisting of a series of individual letters to describe the soil. These properties signify fertility limitations with different interpretations, and represented by small letters (Minh, V.Q. and Tri, L.Q., 2016).

The assessment of the spatial distribution of rice soil fertility and recommendation will support the strategy planning of sustainable soil management. However, the spatial data source for this resource is very limited and difficult to created. It usually has only a spatial map data that can be useful for evaluations. The technology sciences are sharp development, especially GIS technology which helps overlapping, composing, building maps to become easier The objective of study is to apply GIS tool for soil map manipulation and exploitation to delineate the spatial soil databases in terms of fertility, constraints, and recommendations for proper rice soil use for development of the management solutions. The study is based on the relationship between the WRB classification system (FAO, 2006) and the FCC system (Sanchez et al., 2003) with some modifications from Minh, V.Q. (2007) and the power of GIS to map rice soil fertility maps.

2. Methodology

2.1. Data collection

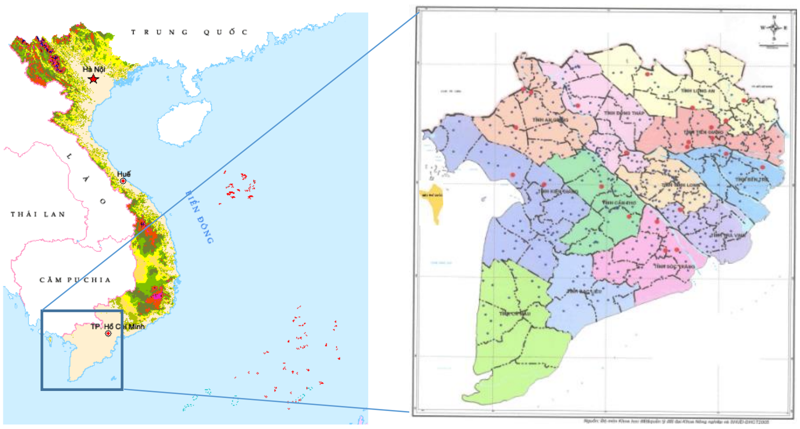

Figure 1: Location of soil data collection in the Mekong delta, Vietnam

- Collection of soil chemical and physical data analysis from 300 soil samples and 423 soil profiles for soil morphology description used for the identification and classification of soil WRB and FCC systems.
- Collection of soil map according to WRB system (2006) in Mekong delta (2014) from the Department of Land Resources, College of Environment and Natural Resources, Can Tho University, Vietnam.

2.2. Fertility capability classification (FCC)

The Fertility Capability Classification (FCC) system from Sanchez et al. (2003), with some modifications from Minh, V.Q. (2007) was used as reference system.

2.3. Determining the relationship between WRB system and FCC systems

Determination of the relationship between the soil diagnostic horizons, properties and materials definition according to WRB classification system (FAO, 2006) with structural and definition of the FCC system (Sanchez et al., 2003; Minh, V.Q., 2007).

2.4. Maps manipulation

- The maps were created based on coordinate reference system: EPSG: 32648, WGS84/UTM zone 48N.
- MapInfo software was used to compose, delineate and manipulate soil fertility maps

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3. Results and Discussion

3.1. Soil of the Mekong delta

The Mekong Delta has been formed mostly by the sediments of the Mekong River during Holocene period. During this period of sedimentation, the sea level has raised and lowered many times. In the rainfed areas, seawater intrudes far inside the Delta during the dry season and the affected areas cover more than 1 million hectares. In the rainy season, although the soil surface is flushed and freshened, the shallow groundwater still remains saline. In the past, as the river changed its course, several river branches in low landscape had been formed and deposits with high sulfur content and organic matter have been deposited, in some areas such as Ha Tien, Dong Thap, Chau Thanh-Vinh Long, Chau Thanh-Ben Tre. In early 1985, a national project called 60-02 (later 60B) was set up to carry out a resources inventories of the Mekong Delta. Within this project, a soil map was prepared at the scale of 1/250,000 for all provinces of the Delta. According to Ton That Chieu et al. (1990), based on the results of the project, 7 main soil types have been identified. Soils were classified according to the FAO (1988 and 1990) system. Soil names represent major chemical and sometimes physical characteristics of various soil types.

Intensive rice cultivation in the Mekong delta, Vietnam is rapidly developing. These developments need better soil information to enable good planning, accurate interpretation of data, and the extension of results to new area. Soil horizons, properties and materials are intended to reflect features which are widely recognized as occurring in soils and which can be used to describe and define soil classes. For WRB purposes the diagnostic horizons, defined in Revised Legend (FAO, 1988), have been used as a basis.

The updated soil map was based on WRB classification system (1998), land use map (all at 1/250.000 scale), and collected soil profiles description, soil data analysis for identification major diagnostic horizons and properties for intensive rice soils of the Mekong delta, which are shows below.

3.1.1. Major soil groups:

Based on World Reference Based system (FAO, 1998), the soil for rice cultivation of the Mekong delta can be classified in 6 major soil groups, including:

- **Albeluvisols** (**AB**): Soils having an argic horizon within 100 cm from the soil surface with an irregular upper boundary resulting from albeluvic tonguing into the argic horizon.
- **Alisols** (**AL**): Soil having an argic horizon, which has a CEC of 24 cmolc kg^{-1} clay or more, either starting within 100 cm from the soil surface, and alic properties in the major part between 25 and 100 cm from the soil surface
- **Arenosols** (**AR**): Soil having a texture which is loamy sand or coarser either to a depth of at least 100 cm from the soil surface
- **Fluvisol** (**FL**): Soil having fluvic soil material starting within 25 cm from the soil surface and continuing to a depth of at least 50 cm from the soil surface
- **Gleysols** (**GL**): which have gleyic properties within 50 cm from the soil surface
- **Luvisols** (**LV**): Soils having an argic horizon with a CEC equal to or more than 24 cmolc kg^{1} clay throughout.
- **Plinthosols** (**PL**): Soil having a plinthic horizon starting within 50 cm from the soil surface

Map of rice soil distribution is delineated in Figure

Detail extend of each soil type in different major soil groups are shown in Table 2.

3.1.2. Diagnostic horizons:

- **Albic E**: is a lightly colored subsurface horizon from which clay and free iron oxides have been removed, or in which the oxides have been segregated to the extent that the color of the horizon is determined by the color of the sand and silt particles rather than by coatings on these particles.
- **Argic B**: The argic horizon is a subsurface horizon which has a distinctly higher clay content than the overlying horizon.
- **Histic H**: The *histic* horizon is a surface horizon, or a subsurface horizon occurring at shallow depth, which consists of poorly aerated organic soil material.
- **Mollic A**: The *mollic* horizon is a well structured, dark colored surface horizon with a high base saturation and a moderate to high content in organic matter

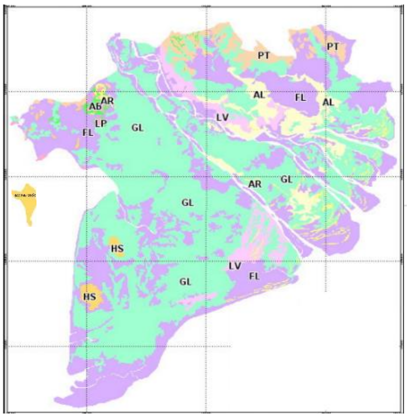
- **Plinthic B**: The *plinthic* horizon is a subsurface horizon which constitutes an iron-rich, humus-poor mixture of kaolinitic clay with quartz and other constituents, and which changes irreversibly to a hardpan or to irregular aggregates on exposure to repeated wetting and drying with free access of oxygen.
- **Salic**: The *salic* horizon is a surface or shallow subsurface horizon which contains a secondary enrichment of readily soluble salts.
- **Sulfuric B**: The *sulfuric* horizon is an extremely acid subsurface horizon in which sulfuric acid is formed through oxidation of sulfides
- **Umbric A**: The *umbric* horizon is a thick, dark colored, base-desaturated surface horizon rich in organic matter
- **Vertic V**: The *vertic* horizon is a clayey subsurface horizon which as a result of shrinking and swelling has polished and grooved ped surfaces ('slickensides').

3.1.3. Diagnostic properties

- **Alic:** The *alic* properties is connotative of very acid mineral soil material with a high amount of exchangeable aluminium.
- **Gleyic**: Soil materials develop *gleyic* properties, they are completely saturated with groundwater, unless drained, for a period that allows reducing conditions to occur (this may range from a few days in the tropics to a few weeks in other areas), and show a gleyic color pattern.
- **Stagnic**: Soil material has *stagnic* properties, at least temporarily, completely saturated with surface water, unless drained, for a period long enough to allow reducing conditions to occur (this may range from a few days in the tropics to a few weeks in other areas), and show a stagnic color pattern

3.1.4. Diagnostic materials

- **Fluvic:** Fluvic soil material refers to fluviatile sediments, which receive fresh material at regular intervals, or have received it in the recent past
- **Sulfidic:** Sulfidic soil material is waterlogged deposit containing sulfur, mostly in the form of sulfides
- **Organic:** Organic soil material consists of organic debris which accumulates at the surface under either wet or dry conditions and in which the mineral component does not significantly influence the soil properties



MAJOR SOILS GROUP CODE	MAJOR SOILS GROUP WORLD REFERENCE BASED (WRB)	LOCAL SOILS NAME
GL	Gleysols	Submerged, gley soils
AB	Alleluvisols	Developed, old alluvial soils
AL	Alisols	Acid soils, high Al in clay
PT	Plinthosols	High Fe clay
FL	Fluvisols	Alluvial soils
LP	Leptosols	Rocky mountains
HS	Histosols	Peat soils
AR	Arenosols	Sandy soils
LV	Luvisols	Degraded soils

Figure 2: Major soil groups of the Mekong Delta (as classified by WRB system)

3.2. The conversion from the soil map (WRB system) to the soil fertility map (FCC system)

In the FCC system which was supplemented by Minh, V.Q. (2007) that identify relationship between diagnostic horizons, diagnostic properties and diagnostic materials in rice cultivation land with some characteristics and constraint factors term in the FCC system. This will serve as a basis for the use of the Soil Map with diagnostic horizons, diagnostic properties and diagnostic materials for transformation into the soil fertility map in Mekong delta province. The basis for conversion is presented in Table 1 and Table 2.

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Table 1: The relationship between Major Soil Groups (WRB system) and characteristics and constraint factors (FCC system) in Mekong Delta.

No.	Major Soil Groups	FCC system					
		Modifers			Soiltexture		
		0-20	20-50	50-100	0-20	20-50	50-100
1	Albeluvisols	-	-	-	C	C	C
2	Alisols	-	-	-	C	C	C
3	Arenosols	k, e and o	k	-	S	S	S
4	Fluvisols	-	-	-	L	L	C
5	Gleysols	-	-	-	C	C	C
6	Histosols	-	-	-	O	O	O
7	Leptosols	k, e and o	k	-	S	R	R
8	Luvisols	-	-	-	C	C	C
9	Plimthosols	-	i	-	C	C	C
10	Solonchaks	s	s	s	C	C	C

Notes: ***C**: Soil Texture is Clay* ***L**: Soil Texture is Loam* ***S**: Soil Texture is Sandy*
***R**: Rock **O**: Organic* ***k**: Ability low supply mineral*
***e**: Ability low nutrient retention* ***o**: Low organic carbon*

Table 2: The relationship between diagnostic horizons, diagnostic properties and diagnostic materials (WRB system) and characteristics and constraint factors (FCC system) in Mekong Delta.

No.	WRB system			FCC system		
	Diagnostic Horizons	Diagnostic Properties	Diagnostic Materials	Modifiers		
				0-20	20-50	50-100
1	Thionic	EpiOrthiThionic	-	a and p	c	-
2	Thionic	EndoOrthiThionic	-	a- and p	-	c^-
3	Thionic	EpiProtoThionic	Sulfidic	-	f	-
4	Thionic	EndoProtoThionic	Sulfidic	-	-	f^-
5	Salic	-	-	s	s	s
6	-	HypoSalic	-	s^-	s^-	s^-
7	-	EndoSalic	-	-	-	s
8	-	Sodic	-	s	s	s
9	Plinthic	-	-	-	i	-
10	-	Rhodic	-	-	i	-

Notes: ***a^-**: Slightly acid* ***a**: Strongly acid* ***i**: High P fixation* ***p**: Possible lack of P*
***s^-**: Slightly salinity* ***s**: Strongly salinity* ***c^-**: Moderately actual ASS* ***c**: Strongly actual ASS*
***f^-**: Deep potential ASS* ***f**: Shallow potential ASS* ***k**: Low mineral supply* ***e**: low nutrient retention*
***o**: Low organic carbon*

The results of soil fertility delineation from manipulation of sol map of the Mekong Delta are shown as:

a^-: from 10 to 60% Al saturation at depth of 50 cm topsoil; This characteristic is mainly in soils with an sulfuric horizon horizon occurring at depths of > 50 cm.

a: Soils with > 60% Al saturation to 50 cm depth of topsoil; or < 33% base saturation at pH 7.0; or pH_{H2O} (1:1) < 5.0.

i: Soils with > 4% free Fe; or > 35% clay or Clay (C) type and mottles with hue = 7.5YR or 5YR or 2.5YR. Corresponding to Plinthic horiozon or Rhodic Properties.

p: applied to topsoil only, with the phosphorus < 2 mg/100g (with Olsen testing method) or < 1 mg/100g (with Bray-II testing method).

s^-: Soils with ECe < 4 mmhos/cm (25 °C) within 100 cm of topsoil.

s: Soils with ECe > 4 mmhos/cm (25 °C) within 100 cm of topsoil.

- **c$^-$**: Applied to Sulfuric horizon with pH_{H2O} (1:1) < 3.5 after drying, with Jarosite mottle and with hue = 2.5Y or yellower, with chroma 6; at a depth of between 50 cm and 100 cm.
- **c**: Applied to sulfuric horizon with pH_{H2O} (1:1) < 3.5 after drying, with Jarosite mottle and with hue = 2.5Y or yellower, with chroma 6; At a depth of <50 cm above ground level.
- **f$^-$**: Applied to potential ASS, soils with pyrite material between 50 cm and 100 cm of subsoil; or have pH_{H2O2} (1:1) < 2.0 in field conditions, no jarosite mottles with hue = 2.5Y at depth from 50 cm to 100 cm topsoil.
- **f**: Applied to potential ASS, soils with pyrite material within 50 cm of topsoil; or have pH_{H2O2} (1:1) < 2.0 in field conditions, no jarosite mottle with hue = 2.5Y at depth of 50 cm topsoil.
- **k**: Soils with low cation base reserves, or low K exchangable; usually < 0.20 cmol/kg of soil; or < 2% if base ≤ 10 cmol/kg of soil. Hence, on sandy soils, the cation exchange capacity is low, and the K content is also low, usually < 0.2 cmol/kg.
- **e**: Applied to low cation exchange capacity (CEC) soils; <4 meq/100g of soil by the method of Σ Base + Al can be extracted by KCl (ECEC), or CEC <7 meq/100g by Σ Cations at pH 7.0, or CEC <10 meq/100g soil by Σ Cations + Al + H at pH 8.2.
- **o**: Applied to topsoil only, with the amount of organic matter < 2% or organic carbon < 1,16%.

3.3. The manipulation of soil map for soil fertility delineation

3.3.1. Delineation of soil fertility distribution

Based on the relationship between diagnostic horizons, diagnostic properties and diagnostic materials (WRB system) and characteristics and constraints (FCC system) from Soil Map of Mekong Delta (2014), the study identified 35 types of soil fertility in Mekong Delta, including: CCC, LLC, CCCf-, LLCf$^-$, OOOf$^-$, CCCs$^-$, CCiC, LLiC, CCfC, CCiCf$^-$, LLfCs, CapCacC, LapLacC, SkeoSkS, SkeoRkR, Cs$^-$Cs$^-$Cs$^-$, Ls$^-$Ls$^-$Cs$^-$, CsCsCs, Ls$^-$Ls$^-$Cf$^-$s$^-$, Ls$^-$Ls$^-$fCs$^-$, CsCsCf$^-$s, LsLsCf$^-$s, LsLsfCs, Ca$^-$pCa$^-$Cc$^-$, La$^-$pLa$^-$Cc$^-$, Oa$^-$pOa$^-$Oc$^-$, Ca$^-$pCa$^-$Cc$^-$f$^-$, CapCacCf$^-$, Ca$^-$ps$^-$Ca$^-$s$^-$Cc$^-$s$^-$, La$^-$ps$^-$La$^-$s$^-$Cc$^-$s$^-$, Ca$^-$psCa$^-$sCc$^-$s, Caps$^-$Cacs$^-$Cs$^-$, CapsCacsCs, LapsLacsCs, CapsCacsCf$^-$s. Therein, the biggest area is the CCC soil fertility (790,734.0 ha, accounting for 20,21%) and the smallest area is the Oa$^-$pOa$^-$Oc$^-$ soil fertility (2,484,8 ha, accounting for 0,06%). Specifically, the types of soil fertility and its distribution are presented in Table 3 and Figure 1. Besides that, the study was identified 11 types of constraints for agricultural cultivation, including Slightly acid (**a$^-$**), Strongly acid (**a**), High P fixation and high Fe toxicity potential (**i**), Low available P (**p**), Strongly actual ASS (**c**), Slightly actual ASS (**c$^-$**), Shallow potential ASS (**f**) Deep potential ASS (**f$^-$**), Slight salinity (**s$^-$**), Strongly salinity (**s**), Ability low supply mineral (**k**), Ability low nutrient retention (**e**), Low organic carbon content (**o**).

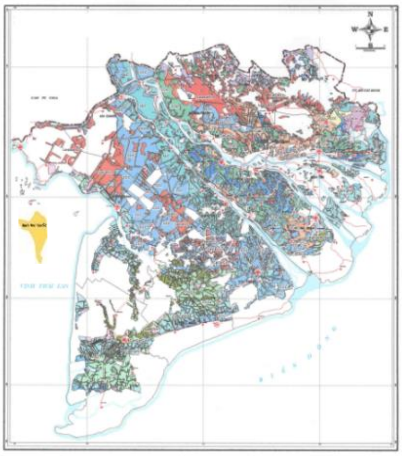

Figure 3: The rice soil fertility map in Mekong Delta

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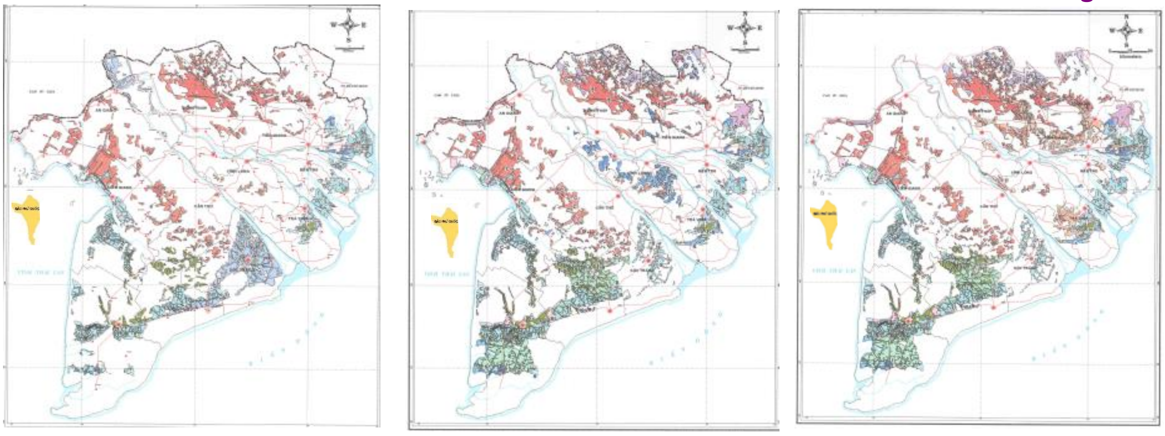

Figure 4: The constraints for rice cultivation in Mekong Delta (at 0-20cm, 20-50cm, and 50-100cm)

LEGEND

Code	Constraints		
	0-20 cm	20-50 cm	50-100 cm
1	Regularly submerged state, H2S toxicity (g+)	Regularly submerged state, H2S toxicity (g+); Strongly salinity (s)	Deeply potential acid sulfate soil (f-); Strongly salinity (s)
2	No constraint	No constraint	Deeply potential acid sulfate soil (f-)
3	No constraint	Strongly acid (a); High phosphorus fixation (i)	No constraint
4	Regularly submerged state, H2S toxicity (g+)	Regularly submerged state, H2S toxicity (g+)	Deeply potential acid sulfate soil (f-)
5	No constraint	High phosphorus fixation (i)	Strongly salinity (s)
6	No constraint	Strongly salinity (s)	Strongly salinity (s)
7	Slightly acid (a-); Low inherent phosphorus content (p)	Strongly acid (a); Strongly actual acid sulfate soil, Al and Fe toxicity (c); High phosphorus fixation (i)	Deeply potential acid sulfate soil (f-)
8	Low inherent phosphorus content (p)	Slightly acid (a-)	Moderately actual acid sulfate soil, Al and Fe toxicity (c-)
9	No constraint	Strongly salinity (s)	Strongly salinity (s)
10	No constraint	Strongly salinity (s)	Deeply potential acid sulfate soil (f-); Strongly salinity (s)
11	Low inherent phosphorus content (p)	Slightly acid (a-); Strongly salinity (s)	Moderately actual acid sulfate soil, Al and Fe toxicity (c-); Strongly salinity (s)
12	Slightly acid (a-); Low inherent phosphorus content (p)	Strongly acid (a); Strongly actual acid sulfate soil; Al and Fe toxicity (c); High phosphorus fixation (i); Strongly salinity (s)	Deeply potential acid sulfate soil (f-); Strongly salinity (s)
13	No constraint	No constraint	No constraint
14	Non-constraint	Shallowly potential acid sulfate soil (f)	Deeply potential acid sulfate soil (f-)
15	Low organic carbon (o)	High phosphorus fixation (i)	No constraint
16	Low inherent phosphorus content (p)	Slightly acid (a-); Strongly salinity (s)	Moderately actual acid sulfate soil, Al and Fe toxicity (c-); Strongly salinity (s)
17	Regularly submerged state, H2S toxicity (g+)	Regularly submerged state, H2S toxicity (g+)	Strongly salinity (s)
18	Low inherent phosphorus content (p)	Slightly acid (a-)	Moderately actual acid sulfate soil, Al and Fe toxicity (c-)

3.2.2. Delineation of soil constraints

Constraints related to soil mineral

- **Potential of high leaching ability (e)**: Soils with a low cation exchange capacity (CEC), low in organic matter, clay content, clay minerals with low CEC, or all these properties, mainly on Arenosol soils group.

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Soils have a low fertility and a low the retain nutrients capability. More N fertilizer application needed; it is usually the identification of degraded paddy soils with low organic matter; if $(NH_4)_2SO_4$ is used as N source, the potential H_2S toxicity can be occurred in coarse texture soils. Besides, Mn deficient can be occurred in coarse texture soils. Application of large organic material keeps pH low even after flooding. Low nutrient capital reserves (**k**) constraints used to be associated.

- **High fixation of phosphorus (i)**: This constraint is caused primarily by a high content of free ferric oxides (Fe_2O_3) in the clay fraction, which fix phosphate ions in unavailable forms. It is a feature also found in strongly acid soils, and hence commonly associated with the **a**, or **a**$^-$ constraint, aluminium toxicity. High P fixation by Fe; P deficiency likely; Fe toxicity potential; soils difficult to puddle and will regenerate original structure rapidly. This is mainly on Plinthosol soil group or ASS with OrthiThionic properties.
- **Low Nutrient Capital Reserves (k)**: Low inherent fertility because of low inherent reserves of wethearable minerals; potential K deficiency depending on base contents of irrigation water. This is mainly on Arenosol soil group.
- **Low status of organic matter (o)**: N deficient; response to N fertilization very likely; low ECEC on sandy soils; N fertilizer should be applied in frequent, small doses. This is mainly on Arenosol soil group.
- **Low content of inherent P (p)**: Plant available P deficient; response to small additions of P fertilization very likely. This is mainly on Arenosol soil group and soils has OrthiThionic properties

Constraints related to soil reaction

- **Low pH, high Al toxicity (a, a$^-$)**: These are soils in which the exchange complex is dominated by alumina. The problem is commonly described as one of strongly acid soils, can be caused by strong leaching from high rainfall, and mainly from oxidation of sulfidic material, which often associated with **c**, **c**$^-$ modifiers. Aluminium toxicity will occur in aerobic layers, mainly on soils has OrthiThionic properties.
- **Actual ASS (c, c$^-$)**: Al and Fe toxicity, low pH, and P deficiency, which originated from the oxidation of sulfidic material.
- **Potential ASS (f, f$^-$)**: Potential acid sulfate soils, which causing Fe and S toxicity when anaerobic and Al toxicity; depth at which **f** modifier occurs determines feasibility of rice production; Zn deficiency can be occurred.
- **Constant saturation (g$^+$):** The prolonged of submergence which causing Zn deficiency. Besides, the increasing of N nutrient loss, if soil is long time of intermittently flooded and drained.
- **Saline (s, s$^-$)**: Saline soils, high soluble salt; drainage needed, testing of soil EC of irrigation water needed.

Table 4. Extent of modifiers and soil fertility constraints of rice soils and the areas in the Mekong delta *(Based on the conversion of rice soil map-WRB at 1/250.000 scale) (Minh, 2004)*

Modifiers	Soil fertility constraints	Area (ha)
p	low available P	327,099.4
s	Strongly salinity of subsoils	327,099.4
a	Acid soil, iron, aluminium toxicity	323,183.1
i$^+$	High phosphorus fixation and high Fe toxic potential	231,628.0
c$^-$	Depth actual acid sufate in subsoil	198,914.3
c	shallow actual acid sufate soils	159,619.2
s$^-$	slightly salinity in subsoils	156,840.9
f$^-$	Potential acid sulfate in subsoil	72,757.0
i	High phosphorus fixation	69,944.7
f	Shallow potential ASS	28,716.8

*(**Note**: Each soil unit can have more than 1 indicator)*

4. Conclusion

Maps manipulation using GIS is a powerful tool to create and delineate several maps for soil fertility classification and evaluation from conversion of soil map based on its relationship. Maps of soil fertility distribution, soil constraints and recommendation were delineated, which can be used for agricultural extension and farmer recommendation. The GIS techniques can be used to exploit the spatial soil resource database for more application.

The applicability of the results depending on the scale, detail of maps used to manipulate.

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