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THE SOIL FERTILITY CLASSIFICATION AND CONSTRAINTS FOR RICE CULTIVATION IN THE MEKONG DELTA

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ABSTRACT

*The areas of intensive rice production in the Mekong delta, Vietnam, have been rapidly enlarged but rice yield tend to be declined or need more fertilizers. Therefore, the degradation of soil fertility in this system can be one of the most important factors contributing to the yield decline. Information on soil fertility and recommendations on improving soil constraints will provide basic data for proper soil management, land evaluation and land use planning. A Fertility Capability Classification (FCC) system incorporated with characteristics of soil morphology, soil physics, and soil chemistry were used for this study. Data from 300 soil profiles from rice fields and 28 field experiments on fertilizers efficiency were collected and analyzed, showing that 25 rice soil fertility types were classified in the Mekong delta, in which types of **CC** (clay in top and subsoil) and **CCs** (clay in top and subsoil and saline effected) occupied in large areas. The major soil constraints for rice cultivation can be listed as follows: low organic carbon content (**o**); high P fixation and high Fe toxicity potential (**i**); potential salinity (s^-); low available P (**p**); high acidity and Al toxicity (**a**); the separation of actual acid sulfate soils (**c**, c^-) and potential acid sulfate soils (**f**, f^-).*

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1 INTRODUCTION

In the Mekong delta, rice cultivation is usually irrigated and highly productive, featuring multiple rice crops. They also faced with serious problems including the unsustainable exploitation of water and soils, inefficient use of chemical inputs, and emerging or worsening disease and pest problems. The intensive cultivation that increased pressure on land led to degradation and pollution of soils, which caused a partial or completed loss of its productive capacity.

According to Sanchez (2001), differences in soil taxonomy are important to establish the broad picture, but what does it mean in agronomic and ecological terms? The problem with soil taxonomy is that it quantifies only permanent soil parameters, most of which are located in the subsoil (Sanchez *et al*., 1982). To overcome this limitation, a 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 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. From that, this study on the integrated system for soil fertility evaluation were carried out in order to use for soil fertility classification and recommendation to rice soil in the Mekong delta, where rice cultivation dominantly applied, which can assist the land use planner or agricultural extension officers to identify the constraints, and recommend for proper use.

2 METHODS

The Fertility Capability Classification (FCC) system from Sanchez *et al*. (2003), with some modifications from Minh (2007) was used as reference system. With 300 top and subsoil samples in rice fields were collected within the Mekong delta from 1996 to 2007 for soil chemical and physical analysis (soil texture, pH, ECe, Al^{3+}, Fe^{3+}, K^{+}, Na^{+}; Ca^{2+}, Mg^{2+}, CEC, organic matter, P available) and soil profile description based on the guideline of FAO (1974), which recommended by the system, and data of 28 field experiments on fertilizers efficiency for rice cultivation from several projects (Hydro, Sarec, MHO8) on soil inventory, fertilizer uses, soil reclamation. Fourteen (14) modifiers that indicate the soil fertility status and effect to rice growth in the Mekong delta were determined as recommended by Minh (2007): **a**, $\mathbf{a^-}$ (Al toxicity, low pH), **c**, $\mathbf{c^-}$ (actual acid sulfate soils), **e** (high leaching potential), **k** (low nutrient capital reserves), **f**, $\mathbf{f^-}$ (potential acid sulfate soil), $\mathbf{g^+}$ (constant saturation), **i** (high phosphorus fixation), $\mathbf{n^-}$ (potential Sodic), **s**, $\mathbf{s^-}$ (saline), **o** (low organic matter status), and **p** (low inherent P content), which affected to rice root zone. In which, modifiers **p**, **o**, **c**, $\mathbf{c^-}$, **f**, $\mathbf{f^-}$ were added by Minh (2007), and superscripts + or **-** indicate a greater or lesser expression of the modifier. The soil fertility was named as soil texture of each soil layer (**C**, **L, S**) plus modifiers.

Figure 1: Location of the Mekong delta in VietNam

3 RESULTS

3.1 Soil fertility classification for rice cultivation in the Mekong delta.

The term "FCC" is used to indicate adaptation of the Fertility Capability Classification, as developed by Sanchez *et al*. (1982), and Sanchez *et al*. (2003), and modified by Minh (2007) to the soil fertility and rice growing conditions in the Mekong delta, in which the system deal with characteristics of soil morphology, soil physic, and soil chemistry. The meaning of each soil fertility type was set up for soil fertility capability classification (FCC), including 25 soil fertility types, which converted from soil map at 1/250.000 scale, to be identified by its corresponding letter and the corresponding limits (Table 1).

Table 1: Summary of soil fertility capability classification (FCC) for rice cultivation and the areas in the Mekong delta (Based on a system from Sanchez *et al*. (2003), Minh (2007) and the conversion of rice soil map – WRB 1998 at scale 1/250.000)

FCC	**Soil fertility capability interpretation**	**Ha**	**%**
CC	texture is clay (**C**) within 50 cm from the soil surface	328,382	18.6
CCs	texture is clay (**C**) within 50 cm from the soil surface, severe salinity in subsoil (**s**)	327,099	18.4
LC	texture is loamy (**L**) between 0 and 20 cm, and a clay (**C**) between 20 and 50 cm	160,013	9.0
CCc$^-$	texture is clay (**C**) within 50 cm from the soil surface, Moderately actual acid sulfate soils (**c**$^-$)	128,952	7.2
CCi$^+$	texture is clay (**C**) within 50 cm from the soil surface, iron toxicity if prolonged, soil submerged (**i**$^+$)	117,015	6.6
CCai$^+$	texture is clay (**C**) within 50 cm from the soil surface, soil is very acid (**a**), iron toxicity, if prolonged soil submerged (**i**$^+$)	109,560	6.1
CCv	texture is clay (**C**) within 50cm from the soil surface, cracking clays(v)	102,027	5.7
LLacp	texture is loamy (**L**) within 50 cm from the soil surface, soil is very acid (**a**), strongly actual acid sulfate soil (**c**), low inherent P content(**p**)	100,863	5.6
LL	texture is loamy (**L**) within 50 cm from the soil surface	61,990	3.4
LLai	texture is loamy (**L**) within 50 cm from the soil surface, soil is very acid (**a**), high phosphorus fixation (**i**)	54,003	3.0
CCacps$^-$	texture is clay (**C**) within 50 cm from the soil surface, soil is very acid (**a**), strongly actual acid sulfate soil, low inherent P content (**p**), slightly salinity in subsoil (**s**$^-$)	44,739	2.5
CCf$^-$	texture is clay (**C**) within 50 cm from the soil surface, moderately potential acid sulfate soils (**f**$^-$)	35,773	2.0
LLs$^-$	texture is loamy (**L**) within 50 cm from the soil surface, potential salinity (**s**$^-$)	30,175	1.7
LLc$^-$	texture is loamy (**L**) within 50 cm from the soil surface, Moderately actual acid sulfate soils (**c**$^-$)	28,494	1.6
CCc$^-$s$^-$	texture is clay (**C**) within 50 cm from the soil surface, Moderately actual acid sulfate soils (**c**$^-$), potential salinity (**s**$^-$)	25,287	1.4
LLfs$^-$	texture is loamy (**L**) within 50 cm from the soil surface, shallow potential acid sulfate soils (**f**), slightly salinity in subsoil (**s**$^-$)	25,210	1.4
LLf$^-$	texture is loamy (**L**) within 50 cm from the soil surface, moderately potential acid sulfate soils (**f**$^-$)	21,749	1.2
LLc$^-$s$^-$	texture is loamy (**L**) within 50 cm from the soil surface, Moderately actual acid sulfate soils (c$^-$), slightly salinity in subsoil (**s**$^-$)	16,180	0.9
LLi	texture is loamy (**L**) within 50 cm from the soil surface, high phosphorus fixation (**i**)	15,941	0.9
CCacp	texture is clay (**C**) within 50 cm from the soil surface, soil is very acid (**a**), strongly actual acid sulfate soil (**c**), low inherent P content (**p**)	14,001	0.7
LLf$^-$s$^-$	texture is loamy (**L**) within 50 cm from the soil surface, moderately potential acid sulfate soils (**f**$^-$), slightly salinity in subsoil (**s**$^-$)	11,472	0.6
LLi$^+$	texture is loamy (**L**) within 50 cm from the soil surface, iron toxicity if prolonged soil submerged (**i**$^+$)	5,051	0.2
CCf$^-$s$^-$	texture is clay (**C**) within 50 cm from the soil surface, moderately potential acid sulfate soils (**f**$^-$), slightly salinity in subsoil (**s**$^-$)	3,760	0.2
LLf	texture is loamy (**L**) within 50 cm from the soil surface, shallow potential acid sulfate soils (**f**$^-$)	3,506	0.2
LLacps$^-$	texture is loamy (**L**) within 50 cm from the soil surface, soil is very acid (**a**), strongly actual acid sulfate soil (**c**), low inherent P content (**p**), slightly salinity in subsoil (**s**$^-$)	15	0.001
		1,771,267	100

3.2 The constraints for crops cultivation

The attribute used in the system is the lower-case letters of the constraints that have been identified for that soil which indicated in the soil fertility type. Based on the field observations, soil analysis of chemical, physical, rice field behavious, and from several field experiments results, the major soil constraints for rice cultivation in the Mekong delta can be identified and grouped as below.

3.2.1 Constraints related to soil mineralogy

High leaching potential (e): Soils with a low cation exchange capacity (CEC) have topsoils with a low organic matter content, a low clay content, clay minerals with low CEC, or all these properties mainly on sandy or Arenosol soils group. These soils have a low inherent fertility and also a low capacity to retain nutrients added as fertilizer. More exacting N management needed; identifies degraded paddy soils and low organic matter; if potential H_2S toxicity can occur if $(NH_4)_2SO_4$ is used as N source; in coarse texture soils often Mn deficient; application of large organic material keeps pH low even after flooding. Low nutrient capital reserves (k) constraints used to be associated.

High phosphorus fixation (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 acid sulfate soil soils 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 organic matter status (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 inherent P content (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

3.2.2 Constraints related to soil reaction

Al toxicity, low pH (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 acid sulfate soils (c, c$^-$): Al and Fe toxicity, low pH, and P deficiency, which originated from oxidation of sulfidic material.

Potential acid sulfate soil (f, f$^-$): Potential acid-sulfate soils, 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 ; prevent seepage from this areas.

Table 2: 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
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
v	Cracking clays soils when working the soil, we meet obstacle because soil usually flood out, rice root can be broken when soil is dry	102,027.1
f$^-$	Potential acid sulfate in subsoil	72,757.0
i	High phosphorus fixation	69,944.7
f	Shallow potential acid sulfate soils	28,716.8

Note: Each soil unit can have more than 1 indicator

Constant saturation (g^+): Prolonged submergence causes Zn deficiency. N loss increased if soil is intermittently flooded and drained for a long time.

Saline (s, s^-): Defines saline soils; drainage needed, consider conductivity of irrigation water.

Potential Sodic (n^-): This soil has a slightly high content of sodium but is low in calcium and magnesium salts causing soil dispersion, puddling, poor infiltration and poor aeration, and if sodium is high in the plow layer, increased probability of surface crust formation. Defines sodic soils; reclaiming with drainage and gypsum applications needed; Zn deficiency common can be occurred.

3.3 Strategies for better utilization of soil and soil fertility conservation

The management requirements are given per interpreted soil property or group of properties. A complete listing of all possible combinations is not given because only a limited number of combinations of soil properties will be found in any area under consideration. At large scale, however, interpretation of the soil properties in relation to farming systems, local expertise or rice varieties could be a valuable extension tool. The management requirements are based on Smith (1989), Sanchez *et al.* (1982, 2003), Minh (2007), field observations, and several experiments in the Mekong delta on soil management, reclamation, fertility adaptation, rice varieties, etc. A description of soil fertility or management constraint identified is given below:

Al toxicity, low pH (a, a^-): Soluble and exchangeable acidity should be removed as much as possible by leaching before applying amendments. Leaching with fresh water is efficient in removing free H_2S0_4, and efflorescences of soluble Fe and Al salts from the soil. Due to directly effected by low pH, and high Al contents (Guong, 1997), on very low soil pH and very high Al, the amount of lime should be changing from 6 to 10 ton/ha (Xuan *et al.*, 1982).

Actual acid sulfate soils (c, c^-): Iron and aluminium or manganese toxicities and phosphorus deficiency are common. Physical properties are very poor. Jarosite mottles occur at 2 to 50cm depth (**c**) or more than 50cm (**c^-**). This soil should not be drained. Draining results in a dramatic decrease in pH. High liming rates (greater than 10t/ha every 3 to 4 years) or long term leaching would then be required for crop production (Breeman and Pons, 1978). The most profitable practice is shallow drainage to grow one crop of a medium-term rice (Xuan *et al.*, 1982).

High leaching potential (e): These soils suffer from a combination of low organic matter content and an coarse texture, resulting in an extremely low cation exchange capacity. Soil management interventions to remedy these constraints are bound to be expensive and often unprofitable as they imply a change in the clay-humus complex through considerable organic matter and/or high activity clay inputs.

Potential acid sulfate soil (f, f^-): When **f** soils are exposed to air and are low in calcium carbonate, FeS_2 is oxidized to ferric sulfate and free sulfuric acid, producing pH values on the order of 2 or 3. Drained acid sulfate soils are extremely infertile. Flooded rice is often grown, since under constantly reduced conditions, the pH is sufficiently high to eliminate aluminium toxicity.

High phosphorus fixation (i): High P-fixing soils can be identified as those with clayey topsoils having red or yellowish colours indicative of high contents of iron oxides, usually accompanied by a strong granular structure. These soils require high levels of phosphate fertilizers or special P management practices.

Low Nutrient Capital Reserves (k): Potassium fertilizers must be added.. Generally these soils have also limited capacity to retain nutrients and the potassium, calcium and magnesium added can be easily lost (Guong, 1997; Hoa, 2003).

Prolong submergence (g^+): Prolonged submergence causes Zn deficiency, especially on all year round cultivation soil remittently flooded and drained. H_2S toxicity symptom can occurred if soil high in organic matter (Ponnamperuma, 1977)

Potential Sodic (n^-): Reclamation requires the replacement of Na^+ on the exchange complex by Ca^{2+} and leaching of Na^+ out of the root zone. Soil permeability and internal drainage must also be improved so the displaced sodium ions can be leached out of the root zone. Common used mineral amendments are phosphogypsum, calcite and other acid-forming salts like iron and aluminium sulfates, limesulphur and pyrites.

Low organic matter status (o): N deficient; response to N fertilization very likely; low ECEC on sandy soils; N fertilizer should be applied in frequent, small doses. Increasing the levels of organic matter in these soils would improve nutrient supply, increase CEC, increase water holding capacity (Moody *et al.*, 2008).

Low inherent P content (p): P management should be considered as a long-term investment in soil fertility, and it is more effective to prevent P deficiency than to treat P deficiency symptoms. P requires a long-term management strategy because P is not easily lost or added to the root zone by biological and chemical processes that affect N supply.

Saline (s, s⁻): Na, Ca, Mg, Cl, and SO_4 are the major ions involved. Presence of soluble salts requires drainage and special management for salt-sensitive rice varieties. Total reclamation of saline soils is often impractical because of the lack of high quality water for irrigation and leaching. Wetland rice production may be an economical alternative.

4 CONCLUSION

A Fertility Capability Classification (FCC) system, based on the work of Sanchez *et al*. (2003), Minh (2007) was used for rice soil fertility in the Mekong delta relies mostly on the topsoil properties that indicate the soil fertility capability and affected rice production and some properties at subsoil which related to topsoil properties. There were 25 rice soil fertility types, in which clay soil texture in both layers and without modifiers (**CC**) and the same as soil with saline (**s**) modifier (**CCs**) occupied largest extent. The major soil constraints for intensive rice cultivation in the Mekong delta including High P fixation and potential Fe toxicity ($\boldsymbol{i^+}$), Potential salinity ($\boldsymbol{s^-}$), Low available P (***p***), acid and Al toxicity (***a***), respectively. However, constraints of actual acid sulfate (***c***, $\boldsymbol{c^-}$), potential acid sulfate (***f***, $\boldsymbol{f^-}$), and low organic carbon status (***o***), are major constraints for intensive rice cultivation in the Mekong delta. The major strategies for better utilization of soil could be the reclamation of acid sulfate and saline soils by leaching saline, acid and soil toxicity, and improving soil nutrient status such as N, P, K fertilizers and organic matter application.

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