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Soil Fertility and Changes in Fertilizer Use for Intensive Rice Cultivation in the Red River Delta and Mekong Delta of Vietnam

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Abstract

Rice farmers in Vietnam's Red River Delta and Mekong Delta are now fully addicted to using fertilizers to sustain intensive rice production. The introduction of high yielding rice varieties in the late 1960's brought with it the ability to grow crops continuously throughout year, and the need to supplement natural soil conditions with both organic and inorganic fertilizers. Rice yields have increased rapidly in the past 40 years. If intensive agriculture is to continue producing the high yields that Vietnam has come to expect, however, proper management of fertilizer use must begin now.

In this study, three intensive rice fields from alluvial soils of the Red River Delta and two from the Mekong Delta were sampled and tested for nitrogen, phosphorus, and organic matter content. The results of the analysis showed that levels of nitrogen were very low in all five fields, phosphorus levels were higher in the Red River Delta in general, and organic carbon levels were low and corresponded with low nitrogen levels. Fertilizer use data was inconclusive, but cropping patterns can be analyzed based on the natural conditions of the field locations.

Based on these nutrient levels, it is apparent that the use of organic matter, in the form of farmyard manure and compost, must be increased to sustain soil conditions suitable for high yielding rice production in the future. Crop rotation between rice and a leguminous crop would also help to maintain healthy soil conditions. The discrepancy between phosphorus levels deserves further consideration.

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Introduction

Prior to 1960, farmers in Vietnam planted one rice crop per year without the use of chemical fertilizers (Thuan and Bo 2001). Yields were low, and Vietnam was forced to import rice to feed its burgeoning population. High yielding rice varieties were first introduced in 1967, allowing farmers to grow multiple crops per year with high productivity. Thus began 'intensive' rice production in Vietnam. Under intensive cultivation, farmers can now produce over 6 tons of rice per hectare, and grow multiple crops per year with high yields and high quality. These new seeds rapidly depleted the nutrients in soil and required farmers to begin using chemical fertilizer inputs to meet their high nutrient needs. With new intensive agriculture techniques and increased fertilizer dependence, Vietnam shifted from, "a traditional 'soil-based' production environment to an intensified 'fertilizer-dependent' production environment" (Bo *et al*. 2003).

Today, Vietnam has grown to be the world's second largest exporter of rice, while feeding it's population of over 80 million on a rice-based diet. New economic pressures since the late 1980's have forced Vietnamese farmers to strive to maintain high annual rice yields through the use of high yielding seeds, chemical fertilizer, and increasing the number of rice crops grown per year. Free market competition with international rice prices and reclamation of agricultural lands for urban expansion and industrialization makes high yielding rice production the only viable option for most rice farmers in Vietnam. Agriculture and forestry make up approximately 21.8% of Vietnam's GDP,

and are an important aspect of the economic and cultural identity of Vietnam (U.S. Department of State 2006).

In the past 40 years, the area of cereal crop cultivation has increased by 40%, but productivity of cereal crops has increased by 247% (Thuan and Bo 2001). This tremendous increase in productivity is due to the introduction of modern varieties along with the increased use of agro-chemicals and new agriculture technologies. Although 850,000 hectares of the International Rice Research Institute's high yielding rice varieties were grown in Vietnam in 1974, national rice yields grew only 1% from 1967 to 1977 (International Rice Commission 2002). At this time inadequate levels of fertilizer were used, proving the importance of proper fertilizer application in reaping the full benefits of high yielding rice varieties.

Prolonged cultivation in this intensive input/output style has large consequences for maintaining soil fertility sufficient for growing rice. Henry D. Foth and Boyd G. Ellis define soil fertility as, "the status of a soil with respect to its ability to supply elements essential for plant growth without a toxic concentration of any element." (Foth and Ellis 1997). Natural soil conditions, as well as changed dynamics brought on by human agriculture, affect the levels of fertilizer necessary to produce the high yields desired in Vietnam.

In Vietnam's two highest rice producing areas, the Red River Delta and the Mekong Delta, farmers have developed various cultivation strategies based on differing soil and human conditions. If not properly balanced, fertilizer use and continuous cultivation will degrade the naturally fertile alluvial soils in these two areas. If unbalanced, the sustained use of high levels of inorganic fertilizers may cause a reduction

in soil fertility and crop yields in the long run. The history of agricultural development in the Red River and Mekong Deltas reflect the differing needs and future prospects for continued intensive rice cultivation in the two regions.

The Red River Delta:

The history of human settlement in the Red River, or Bac Bo Delta dates back to the very origins of the ethnic Vietnamese. From its nutrient rich fluvial soils sprouted the ancient Viet peoples, who settled in the delta and established wet rice cultivation over 3000 years ago. The land there was created through continual run-off and sediment deposition, eventually forming the Red and Thai Binh Rivers. Today, these rivers continue to transform the delta through a combined annual water stream capacity of 130 billion m^3 and annual alluvial mud deposits of over 120 million m^3 (Hien and Thi 2001).

The Red River Delta's 1.5 million hectares cover only 4.5% of Vietnam's total area but is home to 27% of its population (Lam 2006). With an average population density of 3,122 people/km^2 in 2004, the Red River Delta is the most densely populated area in all of Vietnam (Lam 2006). Average farm size per household in the delta is decreasing due to rapid growth in population and urban expansion. The average farm size per 4-5 member household was only 0.28 ha in 2001 (Hien and Thi 2001).

A highly diversified cropping system has evolved in the Red River Delta. The agroecology of the Red River Delta contrasts with that of the Mekong Delta because of the over 1000 year old dike system, which protects much of the agricultural area from the detriments of flood. Construction of irrigation systems, canals, ditches, and roads after 1960 contributed to the expansion of intensive cultivation and growing of 2 and 3 crops

per year. Fields can now be in production throughout the entire year. Irrigation systems built in the 1960's and 1970's also allow farmers to grow a subsidiary winter vegetable crop in higher elevated, lighter soils (Hien and Thi 2001). The cropping pattern of 2 rice crops and 1 subsidiary crop per year covers the largest amount of land in the delta, totaling 547.64 thousand ha, or 63.28% of all agricultural land. The pattern of 2 or 1 rice crop per year covers 194.74 thousand ha, or 22.5% of agricultural land. The pattern of pure subsidiary crops covers 73.82 thousand ha, or 8.53% of agricultural land. Finally, the pattern of 2 or 1 subsidiary crop and 1 rice crop per year covers 20.7 thousand ha, or 2.39% of agricultural land. (Hien and Thi 2001)

In 2000, the Red River Delta produced 6.6 million tons of rice, 20% of the total rice production of all of Vietnam (Bo *et al.* 2003). Increased intensity of rice cultivation in the Red River Delta is responsible for the 30% increase in rice production between 1995 and 2000. During this period, average rice yields increased from 4.4 to 5.5 tons/ ha, while the area of rice cultivation slightly decreased (Bo *et al.* 2003). High yielding rice varieties, increased use of fertilizers, and a rising awareness of the impacts of balanced fertilization allowed for the rapid increase in crop yields during this period.

Although intensity of agriculture has increased in recent decades, the amount of land allotted for rice production in the Red River Delta has decreased since the 1980's. See table 1. This may be a result of several factors in combination. When Vietnam made the shift to a free market economy in the late 1980's, prices for rice sales were opened up to competition with international rice prices. This decreased the profitability of rice farming, especially for farmers unaware of, or inaccessible to modern technologies. Additionally, as rice cultivation increased in the Mekong Delta, farmers in the Red River

Delta were free to diversify into the more profitable sectors of vegetable and spice cultivation, forestry, and aquaculture. Population growth, urban expansion, and increased industry activities have also limited the plot size of fields in the Red River Delta, making yields of rice per household less substantial. Moreover, loans for the increasing demands of farm investments are less likely to be granted to smaller sized farms. With increasing input costs of high yielding rice cultivation, rice is becoming a less profitable and less popular livelihood strategy in the Red River Delta.

Table 1. Land use change in the Red River Delta (Nguen Xuan Cu 2001. Cited in Lam 2006)

Year	Annual Crops	Rice	Perennial	Grazing land	Water body for aquatic culture	Number of crops/yr
1980	731,600 (89.13)	639,200 (77,88)	19,500 (2.38)	21,800 (2.66)	47,900 (5.84)	-
1985	720,185 (88.75)	628,640 (77,47)	16,938 (2.09)	22,455 (2.77)	49,330 (6,08)	1.85
1990	710,285 (88.67)	624,931 (78.02)	20,639 (2.58)	19,858 (2.47)	50,241 (6.27)	1.97
1993	643,021 (89.14)	585,284 (81.14)	25,830 (3.58)	4,284 (0.59)	48,191 (6.68)	2.16
1998	620,906 (86.15)	576,420 (79.98)	48,688 (6.76)	2,263 (0.33)	48,790 (6.77)	2.20
2000	621,793 (84.17)	575,869 (77.95)	61.431 (8.32)	1,633 (0.22)	53,890 (7.29)	2.20

The Mekong Delta:

Large-scale development of the Mekong Delta occurred centuries after that of the Red River Delta. Inaccessibility to water logged low-lying wetlands, which dominate the delta region, minimized historical agricultural development. It was not until the late 19th century, during the French colonial period, that a system of canals began to provide

access these depression areas. After 1975, the network of canals was extended rapidly, providing for concurrent expansion in the area accessible for human settlement and agriculture. Since then, rice agriculture has increased at an unprecedented rate in the Mekong Delta, through both extension and intensification. Ni et al. discuss some of the complex issues that are responsible for this.

> "[The change] from single to multiple rice cropping [was] made possible by the new canals, and driven by interrelated socio-economic changes, particularly population increases (partly through immigration), the national drive towards increased rice production (helped by tax incentives, available credit from banks and the policy of encouraging landless farmers to "tame the wild lands"), and the increase in rice exports under the new free market system." (Ni et al. 2003)

The Mekong Delta is now the largest rice-producing region in Vietnam. It produced 45-50% of the total rice output of all of Vietnam in 2001 (Hien and Thi 2001).

The natural area of the Mekong, or Cuu Long, delta totals 3.9 million hectares. In 1991, agricultural lands accounted for 61.2% of the area, forestry lands accounted for 10.3%, 9.8% was designated for special use, and 18.7% of the area was classified as "other" (Working Paper No. 4 1991). Total rice production in the Mekong Delta has increased consistently since 1976. From 1976 to 1990, total rice production in the Mekong Delta increased from 4.6 million ton to 9.7 million ton, while average rice yields increased from 2.24 ton/ha to 3.77 ton/ha (Working Paper No. 4 1991). In 2000, the Mekong Delta produced 16.7 million tons of rice, 50% of the total rice production of Vietnam, with average yields of 4.24 ton/ha (*BO ET AL.* 2003). Although rice intensification is occurring throughout Vietnam, the Mekong Delta is the only region where the area of cultivated land is increasing. The area dedicated to rice cultivation is decreasing throughout the rest of Vietnam.

Cropping patterns in the Mekong Delta have been greatly altered since the introduction of high yielding rice varieties in 1967. Before 1967, the three main cropping patterns of broadcasting, double transplanting, and single transplanting were most commonly used (Chiem 1994). After 1967, however, high yielding rice varieties enabled farmers to grow rice throughout the entire year. Favorable environmental conditions such as plentiful water, consistent seasonal temperatures, and good soils make three rice crops per year a viable option in the Mekong Delta. Because there is no dike system like that of the Red River Delta, the Mekong Delta soils are replenished annually by the nutrients deposited by river floods. Farmers in the Mekong Delta have learned to live with the flood, and have adopted cropping strategies to deal with the benefits and costs of annual flooding.

In the tide-affected floodplain in the northwest region of the delta, tidal river flows help to replenish nutrients to agricultural soils, while washing away the toxicity of acid sulfate soils. Therefore, soil quality in this region is constantly improving. Nguyen Huu Chiem predicts the tide-affected floodplain as the region with highest sustainable agricultural production capacity in the Mekong Delta (Chiem 1994).

Population density in the Mekong Delta is low in comparison to the Red River Delta. There is an average of 328-505 people/km^2 (Lam 2006). The area of grain produced in the Mekong Delta, however, is over twice as much as that of the Red River Delta. The Mekong Delta grows 3,817 thousand hectares of grain, while the Red River Delta grows 1,264 thousand hectares (Lam 2006). Because exploitation of the soils has been going on for a short period of time, flooding replenishes the soil, and population

density is still low, the Mekong Delta has a great potential for continued agricultural production in the future.

Objectives

The objective of this study is to compare soil fertility, cropping patterns, and fertilizer use in intensive rice cultivation on alluvial soils of the Red River Delta and Mekong Delta. Soil fertility will be compared based on nitrogen, phosphorus, and organic carbon content. Recommendations for sustaining future agriculture productivity will be made based on measured soil nutrient content and observed fertilizer use.

Methodology

The original concept for this study was to visit and interview three intensive rice farmers in the Red River Delta and three intensive rice farmers in the Mekong Delta, sample their fields, and analyze the six soil samples in the lab. The expected methodology had to be altered due to unexpected circumstances during the one month allotted research period. Time constraints eliminated the possibility of doing first hand field sampling in the Mekong Delta, and extensive sampling and interviewing in either area was not possible. Instead of original field sampling and interviewing at three farms, two Mekong Delta soil samples were obtained from Can Tho University's soil science department. Information on fertilizer use is not available on the representative soil samples from the Mekong Delta; however, the staff of the soil science department provided some background information on the use of the fields.

Direct field sampling and interviews with farmers were completed for the three Red River Delta sites. Each of the three sites was visited once. The Red River Delta

sites were visited on April 18 and 19, 2006. Dr. Do Nguyen Hai, a faculty member of Land and Environment at Ha Noi Agricultural University, chose the three communes, Co Bi, Duong Xa, and Dong Du. One farmer was interviewed from each commune, and their field was sampled. Farmers were interviewed on fertilizer use and application, crop variety, yield, and land preparation. See Appendix 1 for the general list of interview questions. Nguyen Duc Hung, lab assistant to Dr. Nguyen Huu Thanh from the department of soil science at the Ha Noi Agriculture University translated the interviews in the field.

Five 100 cm^3 soil samples were then abstracted from the field at five evenly spaced positions representing average growth and land grade. One sample was taken at each of the four corners of the field, at least 2 m from the edge, and one sample was taken from the middle of the field. Samples were gathered with a steel ring, 10 cm deep and 10 cm in diameter. After scraping away the top 1-2 cm of topsoil, each core was taken and then combined, resulting in one sample representing average soil conditions for each field. The samples were then air dried in the department of Environment and Resource Management lab at Can Tho University

The representative field at Co Bi is 600 m^2 and the field at Dong Du is 1620 m^2. The interviewed farmer's field at Duong Xa is 260 m^2, so the neighboring field is included in the sample. The total area of the Duong Xa field sample is thus, 520 m^2. Farming techniques and timing are similar in both fields so results should not be affected. A field size larger than 500 m^2 is desired to obtain average field nutrient levels not affected by abnormal nutrient distribution near the edge of a field.

Once dried, the Red River Delta soil samples were ground and sieved to a 2 mm particle size. All five soils samples were then analyzed for pH, organic carbon content, total nitrogen, and available phosphorus. pH was measured by a pH meter in a 1:5 (V:V) suspension of soil in water (pH-H_2O). Percent organic carbon content was obtained using the Walkley and Black method. Percent organic matter was calculated using a multiplication factor of 1.724, from measured organic carbon results. Total nitrogen was analyzed after digestion, using the L. Th. Begheijn method. Total available phosphorus was analyzed using the Bray method.

Results

Farmer interviews in the Red River Delta resulted in the acknowledged fertilizer use and average yields presented in Table 1. All three sites are located inside the dike on alluvium soil. All three sites have the first rice crop of the year growing in them at the time of sampling. See Appendix 2 for full results from field interviews.

Red River Delta site #1- Co Bi, Gia Lam district, Ha Noi, grows 2 rice and 1 winter vegetable crop per year, and has done so since 1959. This farmer uses the least amount of fertilizer of all of the Red River Delta sites, and reports the highest yields. He claims to try to grow "clean vegetables", referring to the low fertilizer inputs. 20-day-old rice seedlings are transplanted to the field, the first crop on 10 January, and the second crop on 20 June. Both rice crops are high yielding varieties. A vegetable crop of onions or tomatoes is grown for 3 to 4 months during the winter. Since 1959 the farmer has reported increasing yields, decreasing use of organic fertilizer, and increasing use of

inorganic fertilizer. New science and new rice varieties are acknowledged for increased yields. Cultivation techniques are applied based on recommendations from Co Bi commune. The field is 600 m^2, and the current rice growing in the field is approximately 1.06 meters tall. The soil is moist, but not covered in water.

Red River Delta site #2- Duong Xa, Gia Lam district, Ha Noi, grows 2 rice and 1 winter vegetable crop per year. This farmer reports the highest use of inorganic fertilizer out of all of the Red River Delta sites. She has owned the field for four years because Duong Xa commune enacts a 20-year rotation of fields between the farmers in the commune. Young rice seedlings are planted in the field, the first crop was planted on 15 February, and the second crop will be planted on 5 July. Both crops are high yielding varieties. A vegetable crop of onion, mustard green, or kohlrabi is grown in the winter months. The second rice crop receives less fertilizer and has lower yields. She has replaced organic fertilizer with inorganic fertilizer in recent years, for longer than she can remember. Between crops, she prepares the field by ploughing and applying organic fertilizer. All the farmers in the commune apply the same methods and same rice varieties. The field is inundated with 4-6 cm of water, which was pumped in from a nearby canal. The current rice crop is 1.06 meters tall. This farmer's field in 260 m^2, and the total area of fields included in the sample is 520 m^2.

Red River Delta site #3- Dong Du, Gia Lam district, Ha Noi, grows 2 rice crops per year. This farmer rotates 2 rice crops per year with 2 eryngium (long coriander) crops per year, every 18 months. She has owned the field for 16 years. Crop rotation has been going on since 1997, before that, 2 rice crops per year were grown every year. A much higher profit is made from eryngium than rice, and eryngium requires more fertilizer than

rice. The first rice crop was planted on 15 February and the second crop will be planted in the end of June. Both crops are high yielding varieties. Between crops, the field is prepared through ploughing and application of organic and mixed fertilizer. The field is inundated with 5-8 cm of water. The top 10-15 cm of soil is very soft and not dense. Below 15 cm lies a layer of heavier soil. The soil in Dong Du is not suitable for growing vegetables because the subsoil is almost all dense clay and the topsoil is very light. Total area of the field is 1620 m^2, and rice in the field is approximately 1 meter tall. Dong Du is located at a slightly lower topography than Co Bi and Duong Xa.

The staff of the Soil Science department at Can Tho University provided information on the Mekong Delta soil samples. Both samples were taken after harvest of rice.

Mekong Delta site #1- Cai Lay, Tien Giang province grows 3 rice crops per year. 3 rice crops per year have been grown here for many years, probably more than ten. Cai Lay is located inside a dike on alluvium soil. The field has experienced some problems because of changing dynamics of organic matter, which make growing rice more difficult. Physical properties are also degraded. These cause low yield so the farmer must increase fertilizer and pesticide use to grow rice successfully. This soil sample is a gray color compared to the red color of the other four alluvial soil samples.

Mekong Delta site #2- Vinh Nguon, An Giang province grows 2 rice crops per year. The field is located outside the dike on alluvium soil.

Table 1: Fertilizer use and yield in Red River Delta sites, measured in kilograms per 360 m^2:

	#1 Co Bi	#2 Doung Xa	#3 Dong Du
Organic matter	3-5	A little	Amount depends on amount available
Mixed Fertilizer N:P:K=16:16:8	5-7	15	10
Nitrogen	2-3	80	3
Potassium	3	4-5	4
Phosphorous	0	15	0
Average yield of spring rice crop (rice variety)	200-250 (Si23)	180-220 (Si23)	180-220 (Khang Dan)
Average yield of summer rice crop (rice variety)	180-220 (Q5 Khang Dan)	140 (Si23)	140-150 (Q5)

Results from laboratory analyses of the three Red River Delta (RRD) and two Mekong Delta (MD) soil samples provide the levels of organic carbon, organic matter, available phosphorus, total nitrogen, and pH, indicated in Table 2.

Table 2: Nutrient levels measured in soil samples from Red River Delta and Mekong Delta.

	% Organic Carbon	% Organic Matter	Available Phosphorous (mg/kg)	% Total Nitrogen	pH
RRD #1: Co Bi	2.693	4.643	48.347	0.0231	5.69
RRD #2: Duong Xa	1.766	3.045	48.964	0.01792	6.41
RRD #3: Dong Du	2.44	4.207	1.554	0.021	5.49
MD #1: Cai Lay	2.527	4.357	22.712	0.02016	5.70
MD #2: Vinh Nguon	1.905	3.284	2.658	0.01365	5.84

Discussion

Available Phosphorus:

According to Bray standards, the available phosphorus level in Co Bi is high, Duong Xa is high, Dong Du is low, Cai Lay is medium, and Vinh Nguon is low. The two fields with only two crops per year, Dong Du and Vinh Nguon, had the lowest available phosphorus levels. This is most likely because farmers must apply much more fertilizer, including phosphorus fertilizer, to triple cropped fields than to double cropped fields. The fields where vegetables are grown also require more phosphorus fertilizer inputs, resulting in higher observed values. Although Dong Du does grow a spice crop, it is currently at the end of its 18 month rice cycle, so eryngium has not been grown here for almost 18 months and available phosphorus levels are much lower than in Co Bi and Duong Xa where vegetables were grown this past winter.

The fields in the Red River Delta have higher available phosphorus levels than the fields in the Mekong Delta in general. This could be because the soils of the Mekong Delta are naturally more phosphorus deficient than the soils of the Red River Delta. In the Mekong Delta, the soil is more acidic because of oxidation of the pyrite-rich sub-soil, which formed when ancient mangrove forests decayed and decomposed. Acidic conditions cause phosphorus to be fixed into its mineral form, which is not available for plant up-take. Although available phosphorus levels are low, total phosphorus levels may be higher than detected, however, the phosphorus is fixed into a form unsuitable for plant uptake. Total phosphorus was not measured in this study.

Phosphorus levels may also be higher in the Red River Delta because all of Vietnam's phosphorus mines are located in the north of the country. Economically, the incentive to use more phosphorus fertilizer is stronger in the Red River Delta where phosphorus fertilizer is cheap. This also implies that phosphorus is more prevalent in the mineral composition of northern soils.

Organic Carbon:

According to Can Tho University Soil Science department standards, percent organic carbon is low in Co Bi, very low in Duong Xa, low in Dong Du, low in Cai Lay, and very low in Vinh Nguon. These levels correspond to relative levels of total nitrogen.

Duong Xa uses the highest levels of inorganic fertilizers, and reports the use of only "a little" organic fertilizer. A low organic to inorganic fertilizer ratio results in a low percentage of organic carbon content in the soil. Both organic carbon and nitrogen are naturally supplied to soils through plant and animal decomposition and animal waste. With decreased crop residues from high yielding varieties, both organic carbon and nitrogen levels are expected to be low. Fallow time between crops for crop residue and organic material decomposition, which replenishes soils with organic carbon and nitrogen, is not allowed on constantly cropped intensive rice fields.

Total Nitrogen:

According to Can Tho University Soil Science department standards, percent total nitrogen is very low in all five of the fields sampled, but it is lowest in Duong Xa and Vinh Nguon. The low levels in these two fields correspond with very low levels of

organic carbon. This proves that there is very little organic matter, from which organic carbon and nitrogen are derived, in these fields.

In Vietnam's tropical climate, soils are naturally very low in nitrogen. High temperatures and solar radiation lead to rapid oxidation and weathering, which releases nitrogen from the soil as N_2 to the atmosphere. A long history of intensive cultivation, most likely since 1975 or before, means that nitrogen has been removed constantly from soils for over 30 years. Ploughing exposes more soil surface area to weathering and nitrogen depletion, while leaching of nitrogen occurs at high levels. Multiple crops of high yielding rice per year also deplete soil nitrogen levels rapidly. Without returning plant matter to the soil or allowing fallow time for soils to recover, farmers have become dependent on inorganic fertilizer inputs to grow anything on their fields. The lack of biological material for decomposition and nitrogen replacement means that the stores of nitrogen in the soil are continually being removed without being replenished through natural processes. See Appendix 3 for a summary of the nitrogen cycle.

Large dikes in the Red River Delta, and individual field dikes in the Mekong Delta, prevent river flooding from replenishing fluvial deposits to the soil. Although flooding can be detrimental to rice crops, farmers halt the natural mineral deposition and soil fertilization that river waters carry downstream when they build dikes. Nitrogen levels are still very low in Vinh Nguon, however, the only field in the study located outside the dike. This is because the mineral deposits that the Mekong River carries are naturally low in nitrogen.

Although fluvial deposits from the Mekong River are important for maintaining agricultural soils, their benefit is more in maintaining physical properties than in nutrient

deposition, especially of nitrogen. The speed of the Mekong River decreases significantly around Phnom Penh, upstream in Cambodia, so sediment levels are low once reaching the Mekong Delta. An investigation by the Mekong Committee also revealed that the soluble sediments deposited by the Mekong River to the delta per hectare are approximately 1 kg phosphorus, 3.2 kg potassium, 4 kg magnesium, and 50 kg calcium (Uehara et al. 1974). Significant levels of nitrogen were not detected. These low levels are not significant enough to effect plant nutrition. They are also not very surprising considering the low fertility of the parent materials through which the river flows.

Out of the Red River Delta fields, the farmer at Co Bi uses the least amount of inorganic fertilizer and reports the highest yields. There are two possible explanations for this; the farmer may be misreporting his field statistics, or a history of low inorganic fertilizer use and a high organic to inorganic fertilizer ratio could have led to increased yields in this field. Organic matter has been found to be a very important factor in maintaining soil productivity. Bo *et al.* found that if applied at rates of 8-10 tons/crop hectare, organic fertilizers, especially farmyard manure, play an important role in enhancing soil structure, water storage, cation exchange capacity, and biological activity of intensively grown rice fields in Vietnam (Bo *et al.* 2003).

Maintenance of soil structure is especially important for maintaining high yields in triple cropped rice fields. When rice is grown throughout the year, the soil is continuously submerged under water. This leads to many problems in the long-run including reduced water percolation, compaction of soil, slow organic matter

decomposition, slow nitrogen mineralization, intensive reduction, and anaerobic decomposition (Guong et al. 2002). All of these effects seriously inhibit nitrogen absorption by plants, the most limiting factor for high yielding rice. Maintaining high organic matter levels through application of farmyard manure or compost is an important aspect of sustaining long-term high yields for high yielding rice varieties.

Farmyard manure also helps to supply nutrients to the soil, and requires less resources and pollution costs than producing inorganic fertilizer from minerals. For soils low in potassium, applying manure can provide 30-40% of the potassium needed to grow rice (Thuan and Bo 2001). Application of manure also increases the effectiveness and availability of mineral fertilizers such as nitrogen and phosphorus (Bo *et al.* 2003, Thuan and Bo 2001,). Therefore, application of manure usually leads to increased crop yields when applied with inorganic fertilizers (Bo *et al.* 2003).

The high yields reported at Co Bi are thus most likely related to the fact that Co Bi has the highest organic matter (4.643%) and nitrogen (0.0231%) content of all five fields tested.

The soil conditions at Dong Du and Vinh Nguon are not suitable for growing three crops per year. Sufficient water for irrigation, lighter soil texture, and medium to high delta topography are the necessary conditions for growing three crops per year. In the Red River Delta, higher topographic regions are best suited for two winter crops and one rice crop per year, medium topographic regions are best suited for two rice crops and one winter crop per year, and lower topographic regions are best suited for only two rice crops per year (Thanh 2006). Cash crops, such as maize, are grown during the dry season

outside the dikes on sandier soils. Co Bi and Duong Xa are on relatively medium topographic lands of the Red River Delta, and their soil is a lighter texture that is suitable for two rice crops and one winter crop per year. Dong Du is located on lower lying land and is affected by flooding, which limits its ability to grow three crops per year. Vinh Nguon in the Mekong Delta is also not suitable for growing three crops per year because it is located outside of the dike. Floods in this area decrease the profitability of growing a third, summer-autumn rice crop.

Unlike the Red River Delta, in the Mekong Delta, it is possible to grow three rice crops per year. Local rice varieties, such as floating rice, are adapted to growing under annual flood conditions. The monsoon affected Red River Delta is not as suitable for growing three rice crops per year. Strong tropical storms, as well as a large annual temperature amplitude of 12-13° C eliminates the feasibility of growing a third rice crop in the cold winter months (Hien and Thi 2001). This is why the Mekong Delta is now the main focus for increasing rice production in Vietnam's modern push to remain a global leader in rice exports.

Conclusion

The rapid rice yield increases that Vietnam has experienced in the past 40 years are quickly coming to a halt. According to the Food and Agriculture Organization, yield increases decelerated to only 1% per year in 2002 (FAO 2002). Yield stagnation is a problem even with new hybrid rice varieties. An important factor for maintaining the

high productivity that Vietnam has become accustomed to is the proper use of fertilizers for maintaining high yields in the long-term.

Intensive cultivation is very damaging to soil quality if not managed properly. Many farmers, like those in Cai Lay, are already experiencing problems of decreased yields because of soil degradation. This can be very detrimental for farmers' livelihoods because the only solution to decreased yields from degraded soils is to invest more money in even more fertilizers and pesticides to keep yields high. As the balance between raising input costs and stabilizing output cost comes to a close, farmers will begin to lose money because of prior poor soil management.

Due to the surprisingly low values of organic carbon and nitrogen found in the five fields included in this study, it is apparent that the use of organic matter should be increased as a source of fertilization on intensive rice fields in Vietnam. Organic matter must be used in combination with inorganic fertilizers to maintain yields high enough to feed Vietnam's growing population, as well as to produce enough rice for export in the future. Nitrogen is the main nutrient limiting factor for increasing rice yields. Organic fertilizers, in the form of manure or compost, support fertility maintenance by supplying nutrients and enhancing soil physical properties, thus creating the basis for intensive farming by improving mineral fertilizer effectiveness.

Farmers in the Mekong Delta do not use organic fertilizers on their fields. The short history of agriculture in the delta, along with seasonal floods that replenish soils give the Mekong Delta high enough levels of natural organic matter to support current levels of agriculture. In discussion on the Mekong Delta, Vo Tuyen Hoang found that, "if soils in those regions are supplied more cattle manure and green manure in

combination with chemical fertilizer, it is obvious that rice yield will be increased extraordinarily, especially in the winter-spring rice crop" (Hoang 1997). Not only will current yields increase, but farmers will benefit in the long-term if they begin using organic fertilizers now. Without enough organic matter, soil structure and nutrition will be degraded by continuous intensive agriculture, which drains the soil of essential nutrients like nitrogen, phosphorus, and potassium. The low and very low levels of organic carbon found in all five fields in this study prove the need for increased organic matter supply to rice fields in maintaining affective nutrient levels for high yields.

Other than chemical applications, organic material is the main source of nitrogen, the most yield-limiting factor in soil. All five of the fields surveyed in this study had extremely low levels of nitrogen after decades of intensive rice agriculture. The farmers in the Red River Delta are beginning to diversify cultivation by growing a winter vegetable crop or rotating between rice and a spice crop (Dong Du). The ability to grow rice throughout the year has stalled crop diversification in the Mekong Delta, however, it is encouraged for both income security and soil nutrient sustainability.

Crop rotation is not as popular in the Mekong Delta, but is a viable option for future expansion. Crop rotation, especially with nitrogen fixing leguminous crops like mung bean or soy bean, increases the levels of nitrogen in the soil. A two or three year rotation with mung bean or soy bean is highly recommended for rice farmers to maintain soil fertility without spending even more money on expensive agro-chemical. Combining rice cultivation and fish aquaculture is also a new technique, gaining popularity in the Mekong Delta, for diversifying income while rebalancing the nitrogen cycle in rice fields.

Much higher levels of available phosphorus were found in the Red River Delta than in the Mekong Delta. Some possible explanations for this are higher phosphorus inputs or natural resources in the north, and higher acidity in the south. Understanding and explaining the unequal distribution of phosphorus in Vietnam is an important field for future research, and total phosphorus levels should be analyzed in a further study.

Conclusive data on the relative amounts of fertilizer used in the Red River Delta compared to the Mekong Delta could not be obtained through this study. With more time, observation and interviews of hundreds of farmers in each region would provide the current fertilizer use statistics needed to make an objective comparison. It is apparent, however, that the proper balance of nitrogen, phosphorus, and potassium fertilizers needed in specific areas must be understood to obtain optimal rice yields with minimal environmental degradation. In a future study, potassium, microelements, and soil physical properties should also be included in a proper soil analysis.

Through intensification and introduction of new technologies, rice production has grown to be a major source of food security and GDP in Vietnam. Farmers in Vietnam, however, have become addicted to fertilizers for producing rice. With increasing input costs, the importance of high yields for sustaining a net profit has become imperative. Soil conditions after thousands of years of cultivation in the Red River Delta and hundreds of years in the Mekong Delta have already eliminated the possibility of producing rice at high levels without great amounts of agro-chemicals. Both organic and inorganic fertilizers are necessary for maintaining the rice productivity and high yields that Vietnamese farmers have come to expect. The proper balance between different

types of fertilizers must be maintained, and the importance of organic matter in sustaining rice productivity should not be over-looked.

It is important that site-specific scientific research continues to make new discoveries in understanding the proper use of fertilizers to sustain intensive rice cultivation in Vietnam. The gap between expected yields and farmers' actual yields is almost always high, and only 50% of farmers in the Mekong Delta fully understand the use of fertilizer (Thuan and Bo 2001). Most are using excess nitrogen and phosphorus, which is easily leached from soils, causing pollution and eutrophication of waterways.

As Vietnam's population continues to grow and economic activities diversify, the need for proper investment in agricultural management should not be overlooked. Nutrient balances and the affects of intensive rice cultivation are still not fully understood. Farmers are still using fertilizers inefficiently, and future generations will pay the cost through low rice productivity and environmental degradation. The time for correcting the balance between organic and inorganic fertilizers for optimal rice yields and sustainable production is now. Research on nutrient balance must persist to ensure food security and farmers' income stability for continuing the tradition of rice farming in Vietnam.

References

1. "Background Note: Vietnam". 2005. U.S. Department of State. Bureau of East Asian and Pacific Affairs. http://www.state.gov/r/pa/ei/bgn/4130.htm
2. Bui Huy Hien, and Nguyen Trong Thi. *Rice based cropping systems in the Red River Delta and the Mekong river delta in Viet Nam.* 2001. IFA regional conference for Asian and the Pacific. NISF. Ha Noi, Viet Nam. 10-13 December 2001.
3. Do Dinh Thuan, and Nguyen Van Bo. *Tang nhanh su dung phan bon trong qua khu va hien tai.* 2001. In "Khoa Hoc Dat". Issue #0868-3743
4. Duong Van Ni, Edward Maltby, Roger Stafford, To-Phuc Tuong, Vo-Tong Xuan. *Status of the Mekong Delta: Agricultural Development, Environmental Pollution and Farmer Differentiation.* 2003. In "Wetlands Management in Vietnam: Issues and Perspectives". WorldFish Center. No. 1692.
5. Foth, Henry d., and Ellis, Boyd G. *Soil Fertility 2nd Edition.* 1997. CRC Press inc. Boca Raton, FL.
6. *Issues and Challenges in rice technology development for sustainable food security.* International Rice Commission 20th session- keynote address. Bangkok, Thailand. 23-26 July 2002. www.fao.org/docrep/meeting/004/y6651e/y6651e00.htm#Development
7. Nguyen Huu Chiem. *Geo-Pedological Study of the Mekong Delta.* September 1993. In "Southeast Asian Studies" Vol. 31, No. 2.
8. Nguyen Huu Chiem. *Former and Present Cropping Patterns in the Mekong Delta.* 1994. In "Southeast Asian Studies". Vol 31, No. 4
9. Nguyen Thanh Lam Ph.D. *Agriculture in the Red River Delta.* Power point presentation to SIT VNE Mekong Delta: Natural and Cultural Ecology group. Ha Noi Agricultural University. 11 April 2006.
10. Nguyen Van Bo, Mutert, Ernst, and Cong Doan Sat. *Balanced Fertilization for Better Crops in Vietnam.* 2003. Potash and Phosphate Institute/ Potash and Phosphate Institute of Canada.

11. *Red River Delta Master Plan. Draft only*. Vol 1. VIE/89/034. June 1995. Government of Vietnam, Ministry of Science, Technology and Environment. Prepared by Binnie & Partners. Snowy Mountains Engineering Corporation Ltd. AACM International Pty Ltd. Delft Hydraulics.
12. Uehara, G., M. Nishina, and G. Tsugi. *The Composition of the Mekong River Silt and its Possible Role as a Source of Plant Nutrients in Delta Soils*. 1974. University of Hawaii, Honolulu.
13. Vo Thi Guong, Le Van Khoa, Baert Pier. *Some Chemical and Physical Soil Properties of Intensified Rice Fields in the Mekong Delta.* 2002. In "Vietnam Soil Science". ISSN 0868-3743. p. 6-12
14. Vu Tuyen Hoang. *Exploitation of soil and fertilizer potentiality in food production.* 1997. in "Agriculture-Land Resource and Fertilizer using in Viet Nam". Norsk Hydro. TP Ho Chi Minh. Vietnam
15. "Working Paper No. 4" *Mekong Delta Master Plan (VIE/89/031).* August 1991. Government of Viet Nam/ State Planning Committee/ World Bank/ Mekong Secretariat/ United Nations Development Programme (UNDP). Nedeco.

Appendix 1. General outline for farmer interview questions:

1. How big is your field?
2. How many people work in your field?
3. How long have you owned this land?
4. What do you grow here?
5. How many rice crops per year?
6. Which varieties of rice do you grow?
7. How long does each crop take to grow?
8. What is the average yield that you get from each crop?
9. When do you plant and harvest each crop?
10. Which crop is the most labor intensive?
11. What type of land preparation to do you do in between crops?
12. How long have you practiced this?
13. What types of fertilizer do you use?
14. How much of each type?
15. How much of each element?
16. What is the brand name of the fertilizers you use?
17. How is it applied?
18. When was fertilizer last applied, and what type was it?
19. How much does each fertilizer cost
20. Do you use pesticides and herbicides? What brand?
21. How long have you practiced these techniques?
22. What different techniques were used before?
23. What was grown here before this type of cropping pattern was applied?
24. How do you get information on new farming techniques?
25. Are the same techniques practiced by all of the farmers in this commune?
26. Have you had to use more fertilizer in recent years? Which ones?
27. Had yield increased over the past 10 years? Has profit?

Appendix 2. Results from Red River Delta field interviews:

RRD #1- Co Bi Commune, Gia Lam district of Ha Noi city: 18.04.06 10am

- male farmer, Nguyen Huy Hung
- field is 600m2
- 2 main laborers
- owned the farm since 1959
- belonged to his family before that
- grows 2 rice crops and 1 vegetable per year (usually onions and tomato)
- Vegetables grow in 3-4 months in the winter
- Follows the system of the commune
- 1st crop is planted January 10, harvested between May 15 and the end of May. rice type Si23
- 2nd crop planted 20th of June. Rice type Q5 Khang Dan

- Rice planted here is already 20 days old. Was grown from seed in another field and then is transplanted here after 20 days to save time
- Rice is planted by hand in evenly spaced rows approx. 10 cm apart
- 2nd crop has same growing process but different time length. Second crop is shorter because there is more sun
- Fertilizer
    - Manure and Compost 3-5 kg/360 m2
    - Mixed fertilizer (Lam Thao brand)5-7 kg/360 m2
        - N:P:K= 16:16:8
    - Nitrogen fertilizer (Phu My brand) 2-3 kg/360 m2
    - Potassium fertilizer (Imported from other parts of asia) 3kg/360
- Manuer and compost applied first, before rice is planted
- Mixed fertilizer applied 15 days after the planting
- Pesticides and herbicides are sometimes used. Baran and Actara brands
- Commune suggests that all farmers use the same brands and varieties.
- Some households don't have organic matter, so use microorganisms
- Since 1959, changed the type of rice but use the same technique
- Since 1959, increased rice yields because new science and new types
- Use less organic fertilizer now and more inorganic
- 1st crop = 200-250 kg/360 m2 average rice yield
- value of vegetable crop is double that of rice
- Net profit depends of the prices in the market for rice and fertilizer and other inputs
- Current rice prices: State price= 2000 d/kg, private market= 3000d/kg
- 2nd crop is less time and less yield = 180-220 kg/360
- Always grew 3 crops since 1959
- In winter, grow many types of vegetables, depends on the demand in the market
- Conditions of field during sampling:
    - Weather- grey, misty, wet, ~64 F
    - Soil- moist, some pools in right side middle of field
    - ~ 1% of stalks begin to flower
    - Rice is waist high
    - Bundled ~10 stalks together
    - Planted in rows ~10 cm apart
    - Field is surrounded by a small canal on two sides and other fields on tow sides, no water collection/storage tank, so probably irrigated from canal

<u>RRD#2: Duong Xa commune, Gia Lam district of Ha Noi city:</u> 18.04.06 2:30pm

- Female farmer Nguyen Thi Nguyet
- Her field is 260 m^2
- She and her husband work the field
- Has owned it for 4 years
- 20 year rotation of fields among villagers in the commune
- grows 2 rice and one vegetable crop per year (onion, mustard green, kohlrabi)
- Has 2 fields, one to grow sticky rice – K90 variety, and one to grow normal rice- Si23 variety. (normal rice field is the one tested)
- 1st crop 15 February- 20 June

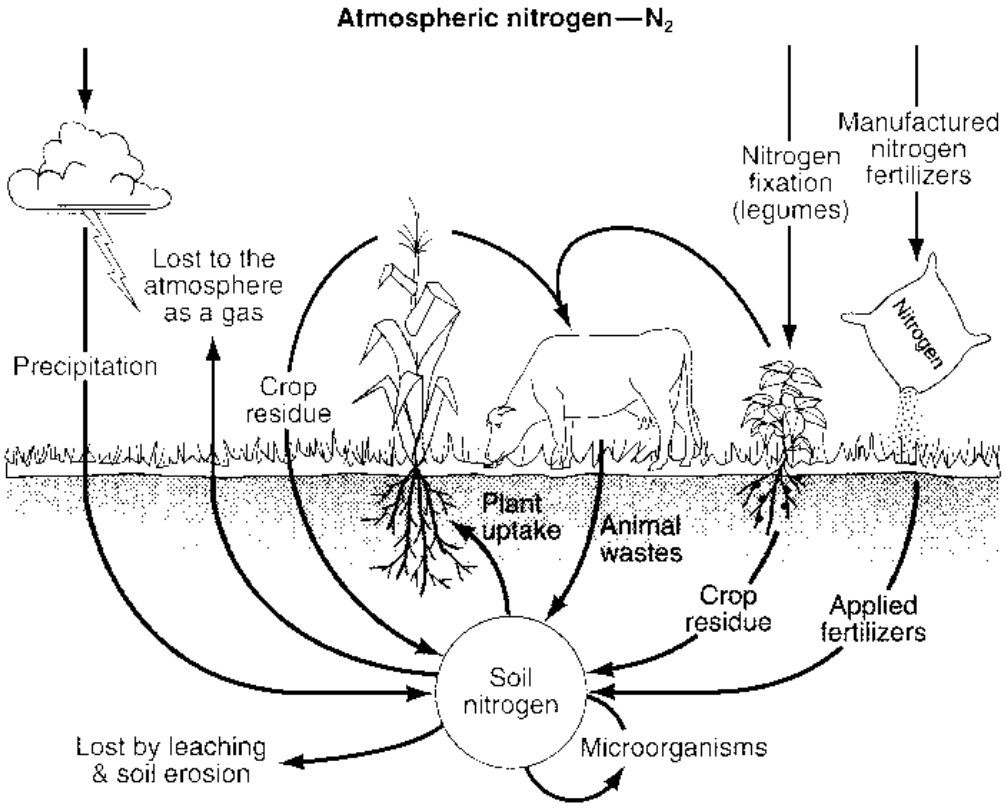
    - last year is was DB5 variety, this year it is Si23 (the crop in the field right now). Next year don't know yet because she is waiting for the recommendation from the commune
- 2nd crop 5 July-15 September
- Plow the field in between and apply fertilizer
- Fertilizer:
    - Ogranic fertilizer (a little)
    - Mixed inorganic (Lam Thao brand) 15 kg/360
    - N-urea 80kg/360
    - Potassium 4-5 kg/360
    - Phosphorous 15 kg/360
- Has replaced organic with inorganic fertilizers more recently, for a long time, cant remember how long
- Husband does the pesticide and herbicide application (Badan brand)
- Urea is the most expensive, mixed fertilizer is the cheapest
- 1st apply mixed fertilizer and organic matter before planting
- If it's cold, have to apply more P
- 5 days after planting (of baby rice, not seed), apply urea
- 2nd crop uses less fertilizer
- 1st crop yield= 180-220 kg/360
- 2nd crop yield= approx 140 kg/30
- Sticky rice is lower yield. Ave 1st crop yield is 120-130 kg/360, 2nd crop is 100kg/360
- Two rice crops per year are the same variety
- Makes about the same profit off of both fields because sticky rice is lower yield but higher selling price at market
- Normal rice is Si23
- Last fertilizer application is K fertilizer ~ 2 mo before harvest
- 30 days after planting, apply N and mixed fertilizer
- She applied potassium fertilizer 3-4 days ago
- Others in the commune do the same
- It was a government decree to rotate fields
- Has owned this field for 4 years, will own it for 20 years total
- This past winter, she grew onions and tomato
- Bring water from the canal manually or with a pump to irrigate
- Field conditions:
    - Weather: Cold, wet, light rain, ~63 F
    - Field is under 4-6 cm of water
    - Rice is waist high
    - Each field is 260m2, seperated by 15 cm mound, two fields included in sample
    - Lots of moss/grass on top of soil

<u>RRD #3: Dong Du commune, Gia Lam district of Ha Noi city:</u> 19.04.06 8:30am

- Female farmer Nguyen Thi Hoa

- Field is 4.5x360 m2
- Has had field for 16 years
- 2 rice/year, rotate this with spice crop
- 1st rice planted 15 February- Khang Dan variety
- 2nd rice planted at end of June- Q5 variety
- each crop takes 100 days to grow
- 1st crop yield 180-220 kg/360
- 2nd crop yield 140-150 kg/360
- She gets a higher profit from Khang Dan (1st crop)
- In between crops, plow field (turn over dirt) and apply organic fertilizer (the amount depends of the amount of cattle waste she has) and mixed fertilizer
- Organic and mixed fertilizer applied to field before planting
- 10 kg of mixed fertilizer – brand Van Dien ....ratio??
- plant rice and apply urea and potassium
    - Urea= 3kg/360
- after 40-45 days apply 3 kg urea and 4 kg potassium fertilizer/360...and none more until harvest
- Applied Urea and K 10 days ago
- P is in the mixed
- Plan to rotate cultivation has been done since 1997
    - 18 months grow vegetables/spice
    - 18 months grow rice
- Before 1997, only rice was grown
- Before february 15 this year, spice was grown here
- Must use more fertilizer for vegetable/spice
- Field Conditions:
    - Weather- foggy and grey ~69 F, rained latter in the day
    - Field covered in 5-10 cm of water
    - 10-15 cm soft soil (85% of sample) and firmer soil below
    - rice ~ hip height, no flowering
- commune farmers association recommends to farmers, they learn from district farmers association
- SPICE= Eryngium (sage) ...mui tau
    - Much higher profit from sage than rice, and more than from other vegetables
    - Grown under a shade structure

<u>Appendix 3.</u> The Nitrogen Cycle



(http://agri.atu.edu/people/Hodgson/FieldCrops/Chapter7.htm)