Diversification and transformation of Asian paddy rice fields to upland vegetable production

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Paddy rice fields cover large agricultural areas in tropical and subtropical Asia. Lower profitability of rice cultivation has, however, created a need for diversification of some of this land to upland crop production, and particularly to the more profitable cultivation of vegetables. Investigations undertaken in a three-year study of permanent vegetable cultivation in a typical rice environment in Southern Taiwan show that adverse soil-related conditions of wetland paddies principally prevail after transformation to upland vegetable production, and that some negative biological processes are even accentuated. Poor water balance, low availability of nitrogen from fertilizers through restricted nitrification but high immobilization, and deficiency in micronutrients occur as a result of soil degradation through long-term rice cultivation. This is particularly true under anaerobic soil conditions.

As the first cultivated crop in Asia about 5000 years ago, rice has admirably supported dense populations for long times. Although it is generally senseless to supplant rice with other crops, declines in rice production profit-ability in some less developed parts of Asia have increased demand for complementation of rice with other crops. Narrowing margins of rice profitability and reduced farmers' income have several reasons:

- Despite governmental protection of domestic markets and subsidies for some production factors, (e.g., fertilizers) rice prices are continually declining for decades, whereas costs are steadily rising.

- Further essential increases in yield potentials of new rice varieties, as achieved during the »Green Revolution«, were not possible anymore in recent decades.

- A decline in rice yields despite introduction of high yielding varieties has been observed under intensive long-term production, heralding degradation of soil re-sources over the long run.

Rapid economic growth in the better developed parts of Asia has created changes in food consumption habits. An increasingly greater demand for alternative food crops, in particular for vegetables, makes conversion of rice fields reasonable in this environment. Due to these factors, significant transition of rice monoculture to multiple cropping systems can be observed all over Asia.

Diversification of paddy rice fields to upland vegetable production

Since long ago, paddy rice has been grown in many parts of Asia with two rainy season monocrops, one in spring and one during the summer, with a short time lag in the rainy (summer) season and a long fallow period between both crops during the dry (winter) season. Vegetables or non-rice crops can be introduced into this traditional cropping pattern at different levels of intensity over *time* and *space* (Figure 1):

Diversification over time.

(1) Probably the most common but least intensive diversification practice in rice production is to cultivate one or more upland catch crops between harvest of one years' second (summer) rice and transplanting of the next years' (spring) crop. Vegetables can be grown without little difficulty during the dry and cool winter months fallow period, particularly in the mild, subtropical winter if irrigation is available. This leads frequently to overproduction. Therefore, market demand and economic returns to farmers usually remain low.

(2) Without affecting crop duration for either rice crop, the short time lag (about

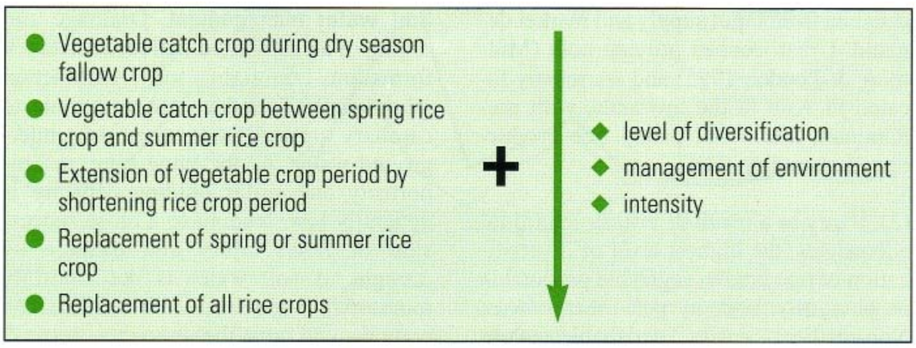

Figure 1: Diversification of Asian rice cropping pattern to vegetable production.

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1 month) between spring and summer rice can be used for a short season vegetable crop. Great market value but high production risks prevail during this period.

(3) Cool-temperature-tolerant varieties, early-maturing varieties, and use of older rice seedlings are means to extend the nonrice growing duration. Although the rice crop per se is not sacrificed, yields are definitely being reduced. Vegetable crops can, however, be accommodated later in spring and earlier in summer or autumn, thereby avoiding the low-price winter season.

(4) There are discussions whether it is more profitable to replace either the spring or the summer rice crop: It is generally more risky to cultivate vegetables during the peak rainy season, but it is the summer rice crop that yields much lower than its spring counterpart due to the impact of adverse rainy season weather.

(5) Complete replacement of rice in a years' cropping season is the most intensive diversification measure. Since land is still reverted periodically to rice, it is the frequency of rotation (usually one rice crop every 3 — 5 years) that determines the intensity of this system. A broad mixture of the above-mentioned diversification schemes exists all over Asia.

Diversification over space. Cropping patterns in paddy fields are governed by (1) *water supply* and *irrigation facilities.* Within this framework (2) *regional location* (lowlands or highlands, distance from urban centers), and (3) *arrangements* within a farmers' land, and monocrop or intercrop) determine the level of diversification intensity:

(1) Fresh market vegetable production essentially depends on *irrigation,* even within the rainy season, paddy fields and not rainfed rice areas should be transformed to vegetables.

(2) Constraints to vegetable production are numerous but likely to increase with distance from input supply and market demand. Urban centres provide both (Midmore & Poudel, 1995) and are mostly located in Asia in the lowlands, with predominant traditional paddy rice production surrounding them.

(3) Partly as a result of infrastructural inadequacies, the highest level of diversification of rice land to vegetable production is obviously best in peri-urban, areas. Non-resilient easily perishable, short growth-duration leafy vegetables are

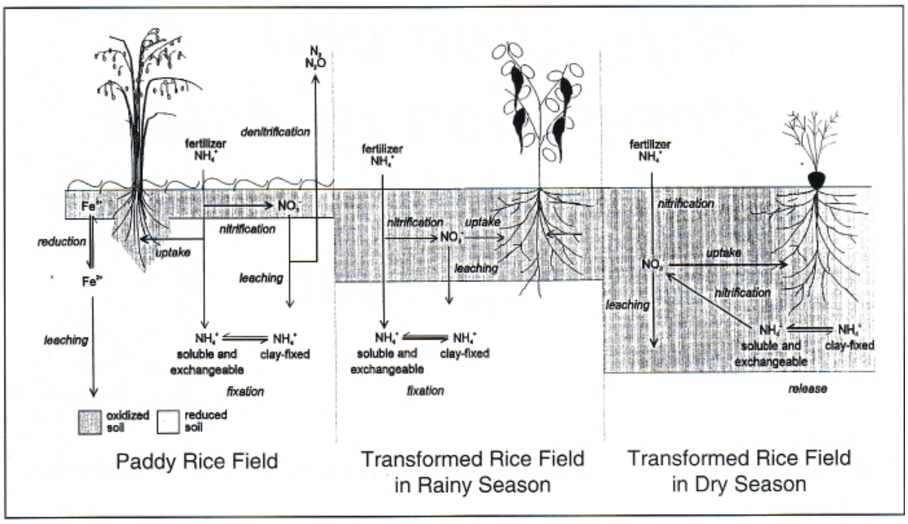

Figure 2: Soil-related processes in the transformation of paddy rice fields to upland vegetable production.

grown in intensive rotations or complex intercrop combinations on farms of very small sizes, replacing rice almost completely. Comparatively highest agricultural incomes are achieved in these most intensive vegetable farms. Above all, farmers' knowledge and experience in cultivation through specialization leads to higher productivity compared to farmers who only grow vegetables occasionally or on a small scale.

Transformation of the paddy rice field environment to upland vegetable production

Rice soils are often alluvial, and low in organic matter. Long-term wet plowing (puddling) creates a degraded, single-grained structure of surface soil on top of a hard plow pan in the compacted subsoil. Transition of this environment to a system suitable for cultivation of vegetables particularly for the wet season is not simply done by allowing the paddies to drain. Soil water and soil fertility are the most crucial factors for successful management of vegetable production in transformed rice fields.

Soil water management. Drainage and drying of a paddy field will result in crack formation through soil contraction (shrinkage). This does not contribute to capillary upward movement of underground water. At the same time, macroporosity and water holding capacity is generally low, leading to a close succession of flood injury and damage by drought, if soil water is not carefully monitored. Even small rain showers can compact and crust the uppermost topsoil, causing a major obstacle to direct-sowing practices of mostly small-seeded vegetables in rice soils.

Since vegetables put an extremely high demand on balanced water supply, raised beds are an essential measure to en-sure good moisture management. Greater bed height provides quicker drainage in the rainy season, that can hardly be achieved by other means. Greater susceptibility to drought in the dry season, or even during prolonged periods without precipitation within the rainy season, can, however, be overcome by irrigation, necessary for vegetable production.

Soil fertility management. Rice is one of the few plants that is more effective in absorbing ammonium-nitrogen (NH_4^+) than nitrate-nitrogen (NO_3) throughout its life cycle (Scarsbrook, 1965). Roots of dichotyledonous plants are, however, less effective in utilizing NH_4^+ but absorb NO_3^- considerably more rapidly (Nommik, 1965). For the cultivation of vegetables it is, therefore, essential to change the poorly aerated, reductive wetland environment to well-aerated, oxidized upland soil conditions. Studies on fertilizer use, crop residue management, and green manure management to maintain soil fertility and to provide plant available (NO_3) nitrogen for vegetables have shown that soil reductive conditions still prevail after transforming a rice field to an upland environment.

Fertilizer management. Aerobic sites in *flooded rice soil* are minimized to a thin oxidized surface soil layer and the rhizosphere of the rice plant root. Nitrogen losses will occur if fertilizer-derived NH_4^+-N is biologically oxidized to NO_3^--N in these sites, which is then leached into underlying anaerobic soil layers to be possibly denitrified to nitrous gas (Savant & de Datta, 1982).

Clay minerals such as illite or vermiculite have strong ability to immobilize ammonium through fixation. Although ammonium is much less mobile in soil then nitrate, most of this fixation occurs in subsoils (Allison et al., 1953). If fertilizer-NH_4^+ is added to the soil, a part of it will be fixed in the clay fraction. When the NH_4^+-concentration in soil solution is, however, depleted to low levels by high uptake of plants, this fixed NH_4^+ will be released (Keerthisinghe et al., 1984).

Besides its effect on macronutrients, low redox-potentials in flooded rice soils also affect the state of micronutrients such as iron (Fe) and manganese (Mn). In the case of iron, insoluble ferric iron (Fe^{3+}) is reduced to plant available, but easily leachable ferrous iron (Fe^{2+}) through microbial action (Neue & Scharpeseel, 1984).

If this wetland rice environment is converted to *upland vegetable production* (Figure 2), organic matter that accumulates much greater under anaerobic conditions is oxidized and decomposed rapidly. Any type of physical disturbance (tillage, weeding) will cause a stimulation of mineralization. As a result, organic matter is depleted and massive losses of (NO_3^-) N may occur through leaching after heavy rainfall, or when the field is shifted back to flooded rice production.

In general, ammonium fertilizers are quickly nitrified under aerobic soil conditions. However, if the soil remains wet for a prolonged time, as it is normally during the rainy season, oxidation to nitrate is largely inhibited. Since fixation of NH_4^+ is higher in drained soils than in flooded soils (Savant & de Datta, 1982), N-fertilization of highly demanding vegetables in converted paddy fields can be ineffective. In our investigation of year-round vegetables with a cropping sequence of four intensive vegetable fresh market crops – carrot, vegetable soybean, Chinese cabbage and chili – plant available (NO_3) nitrogen followed an annual process of fertilizer-nitrogen immobilization and remobilization (release from the fixed sites and nitrification). Higher soil water contents and thus, less aeration and lower redox-potentials inhibited immediate nitrification of added ammonium in the rainy sea-son (Figure 3) so that a larger quantity of NH_4^+ was held in the clay fraction and, consequently, more fixed N was remobilized during the dry winter (Figure 4). Alternatives to the most cheap and readily available ammonium fertilizers are:

(1) nitrate fertilizers which must be applied in many small split doses in order to avoid excessive leaching during the rainy season,

(2) slow-release (coated) fertilizers, but these are either unavailable but always expensive in most tropical regions.

High concentrations of reduced Fe and Mn in soluble and plant available form can lead to toxicity in upland crops following rice. On the other hand though, the solubility of the ions may result in leaching under flooded rice cultivation, making them deficient for upland crops in rotation. In our studies, ferrous sulphate spray solutions were applied to seedlings of Chinese cabbage before planting. Direct-sown carrots showed strong signs of Fe deficiency by leaf chlorosis.

Management of crop residues and green manure. Low redox potentials in rotated paddy rice fields create conditions highly unsuitable for incorporation of fresh organic materials. Externally added organic matter to *flooded rice soils* will accelerate soil reductive conditions through oxygen consumption of decomposing residues. Root injury to seedlings followed by stunted growth has been observed for rice in waterlogged soils containing readily decomposable organic matter (Patrick et al., 1964), and for subsequent crops other than rice, if anaerobic conditions were not eliminated (Cannell & Lynch, 1984). Addition of organic material will further degrade wetland soils by lowering redox-potential leading to dissolving and *leaching of micronutrients* (Fe, Mn). In addition, depleted soil oxygen through excessive application of readily decomposable plant biomass has been found to increase NO3--reduction through denitrification (Patrick & Wyatt, 1964).

In *non-rice based cultivation systems*, »soil-fatigue« is a very well known phenomenon that can be attributed to the accumulation of potentially phytotoxic volatile fatty acids (VFAs) that appear more severe and long-lasting with maturity of crop residues in heavy, waterlogged and poorly aerated soils particularly at cool temperatures (Patrick et al., 1964). Toxic effects of decomposing vegetable tissues on the same or different crop species are known e.g. lettuce (Amin & Sequira, 1966) and Chinese cabbage (Kuo et al., 1981). Phytotoxic substances may reach levels which kill seeds, transplanted seedlings, or even maturing plants. Incorporation of carrot crop residues in late winter in our studies resulted in poor germination and emergence of direct-sown vegetable soybean. Final plant densities and yield were already reduced by 10 percent through addition of 1.0 kilogram per square meter (kg/m2) residue material.

Longer-term negative effects were evident even after four months. Yields of the second Chinese cabbage crop after carrot residue incorporation were significantly reduced by 45 percent marketable yield per 1.0 kg/m^2 material. The same was true for Chinese cabbage residues. Within a time-frame of nine months, yields of two succeeding crops were reduced. Also: Chili following addition of organic matter was increasingly significantly influenced throughout its harvest period resulting in 27 per cent reduction in total yields by 1.0 kg/m^2 residue material (r^2 = 0.10). Even the following carrot crop was affected by of 21 per cent per 1.0 kg/m^2 Chinese cab-

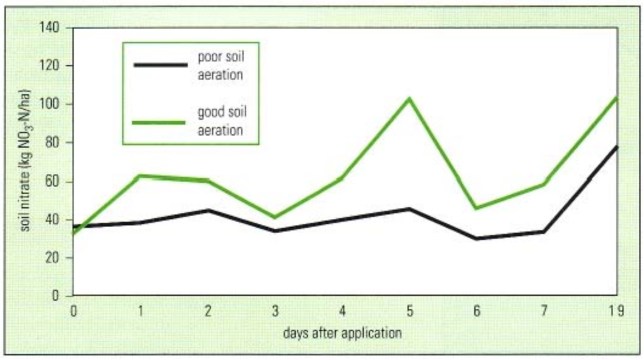

Figure 3: Influence of soil aeration on nitrification of ammonium fertilizer during rainy season

Figure 4: Influence of soil aeration on soil mineralized nitrogen during a 1-year vegetable cropping sequence

bage residue ($r^2 = 0.15$). High-N vegetable soybean residues did not produce any effect on succeeding Chinese cabbage yield ($r^2 < 0.01$).

Immobilization of plant available soil nitrogen has usually been associated with the C/N ratio of added organic material (Stojanovic & Broadbent, 1956). Addition of energy-rich residues (with a high C/N-ratio, such as rice straw) may result in a serious depletion of soil mineral N through build-up of microbial biomass which decomposes the residue (Okereke & Meints, 1985), particularly in the early stages of decomposition. Within a period of approximately two months, incorporation of low-N crop residues (carrot) and high-N crop residues (vegetable soybean) resulted in a similar sequence of initial immobilization of mineral soil (NO_3) N, and a period of nitrogen release during later decomposition.

Many efforts have been made to introduce *green manure* practices to all sorts of crops and by all kinds of methods (cover crops, living mulches, hedgerow systems, ...) to increase N availability and to maintain or increase soil C. The difference in N content (narrower C/N-ratio) between crop residues and green manures is expected to explain differences particularly in soil inorganic available nitrogen. Nevertheless, long-term application of large quantities of green manure could not hinder the depletion of organic matter in some Japanese rice soils, and soil reductive conditions were even more accelerated (Watanabe, 1984a). Under these conditions, decomposition of green manures will result in the formation of phytotoxic organic acids (Tsutsuki & Ponnamperuma, 1987; Toussoun et al., 1986). To avoid damage from their intermediate decomposition products, winter green manure has to be incorporated several weeks before planting rice seedlings in China, although it is usually said that the quick decomposition process of fresh green manures would make its nitrogen immediately available and the market crop should be planted soon after incorporation (Singh, 1984).

In a soil that is temporarily waterlogged, green manure can accelerate denitrification of soil NO_3-N through provision of energy material enhancing build up of denitrifying microbe biomass. Immobilization may be of significance even when high-nitrogen-containing material is added to soil (Stojanovic & Broadbent, 1956) and this might explain why C/N-ratios are not always suitable to predict de-composition rates (Elliott & Papendick, 1986). The effect of green manure applications on soil inorganic (NO_3) N in our study was determined by temperature: in-corporation early in the season resulted in massive initial immobilization of soil nitrate and virtually no release (Figure 5). As temperatures rose towards summer, the immobilization phase became shorter in time and smaller in magnitude, and the release phase was more pronounced.

Use of living mulch adds a component of direct interspecific competition between mulch and vegetable to the soil-related influences of green manure decomposition. With progressive growth of the live mulch, performance of the vegetable will likely be negatively affected.

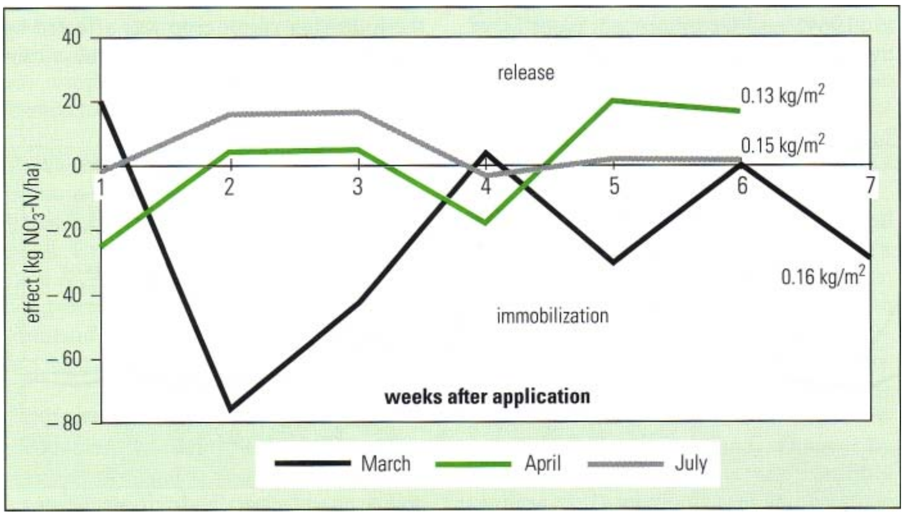

Figure 5: Influence of season on N-release of green manure *(Centrosema pubescens* Benth. and *Desmodium intortum* (Mill.) Urb.)

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