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DIVERSIFICATION AND TRANSFORMATION OF ASIAN PADDY RICE FIELDS TO UPLAND VEGETABLE PRODUCTION

by

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Paddy rice fields comprise the major part of agricultural lands in tropical and subtropical Asia. The need for diversification of some of this area is clear since the income of farmers who depend solely on the produce of their traditional monocrop rice pattern is decreasing due to narrower margins of profitability and changed food consumption habits. Introduction of vegetables as profitable upland crops to the rice-based cropping system is favoured by many options. With increasing levels of intensity over time, vegetables can be introduced as catch crops between rice, or can replace rice crops during a cropping year.

Vegetable crops are luxurious consumers of production factors. This emphasizes the need to produce in the peri-urban peripheries of the big cities, since sources of material supply and market demand are close at hand. Greater agricultural income can be achieved by farmers if rice is substituted by vegetables. It should, however, be pointed out that adherence to a rotation with rice might protect against outbreaks of pests and diseases.

In a four-year continuous vegetable production sequence at the Asian Vegetable Research and Development Center (AVRDC) in tropical Taiwan we studied management-related factors in the transformation of the paddy field environment to upland vegetable production. The results show that soil factors characterizing paddy rice cultivation principally prevail after transferring the wetland fields to conditions of upland production. Long-term rice cultivation has degraded soils, such that they are highly susceptible to flooding in the rainy season, but with low water-holding capacity during the dry season. Improved water management through use of high beds and irrigation has to be emphasized in this environment.

Common problems of plant nutrition in rice cultivation such as N-loss through denitrification, immobilization of N, and solubilization of micronutrients are not eliminated by transfor-

ming a paddy field to upland conditions: accumulated organic matter decomposes rapidly under soil oxidative conditions and nitrogen may be released from fixing sites of clay minerals, both processes leading to accumulation of nitrate in the dry season when leaching is minimal. This nitrogen is quickly lost after rainfall or when the fields are shifted back to rice. However, effects of N availability on vegetable growth appeared only secondary when water stress inhibited efficient N uptake of crops. Therefore, management of soil water is of primary importance in this environment.

Although use of crop residues and green manure has recently been proclaimed as a solution to maintain "sustainability" in agricultural crop production, in transferred paddy fields they worsen soil reductive conditions. Decomposition of crop residues can result in accumulation of phytotoxic products (volatile fatty acids) when they decompose unaerobically. These compounds are finally turned over to methane and CO_2, with consequent implications for the "greenhouse effect". This process has usually been ascribed to waterlogged soil conditions and cold temperatures in moderate climates. The current investigation, however, shows that the consequences of anaerobic soil conditions principally prevail in transformed rice soils in tropical and subtropical environments. Incorporation of crop residues resulted in longer term detrimental effects on seed germination and productivity of succeeding crops. Decomposition of green manure material was shown to depend on temperature: incorporation in the cooler winter resulted in immobilization of soil N, whereas in the summer N release was more emphasized. In less intensive cropping systems these practices may have some value. However, in continuous vegetable production as it is common in many peri-urban lowland zones in Asia, they are likely not to succeed.

Diversification of Asian paddy rice fields to upland vegetable production

As the first cultivated crop in Asia about 5,000 years ago, rice has admirably supported dense populations for long times (Bradfield, 1972), and it will remain the main staple food in the Asian's diet. Recent projections show that 70 percent more rice will be needed in 2025 than in 1995 and governments (e.g., in Vietnam) may increasingly protect rice-cultivation area against other uses. However, declines in rice production profitability have increased demand for diversification, i.e., demand for complementation of rice with other crops. Narrowing margins of rice profitability and reduced farmer's income have several reasons (Pingali, 1992):

- Despite governmental protection of domestic markets and subsidies for some production factors (e.g., fertilizers), rice prices have been 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", could not be attained 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 resources and environment by rice monocultures over the long run. Less intensive farmer's fields are partially outyielding experimental stations.

Rapid economic growth in the better developed parts of Asia has created changes in food consumption habits. Since the 1950s, rice consumption in Taiwan has decreased about 50 percent, whereas vegetable consumption has almost doubled. Less demand, but advanced cultivation techniques have resulted in expensive rice over-production. An increasingly greater demand for alternative food crops, in particular for vegetables, makes conversion of rice fields reasonable in this environment and can be observed all over Asia (Tu, 1986).

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 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 (Su, 1981; Table 1) and space.

Table 1 — *Diversification of Asian rice cropping pattern to vegetable production*

• **Vegetable catch crop during dry season fallow period** • **Vegetable catch crop between spring and summer rice crop** • **Extension of vegetable crop period by shortening rice crop period** • **Replacement of spring or summer rice crop** • **Replacement of all rice crops**	**+** ↓ • **level of diversification** • **management of environment** • **intensity**

Diversification over time

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 year's second (summer) rice and transplanting of the next year's (spring) crop. Vegetables can be grown without little difficulty during the dry fallow period, particularly in the mild, subtropical winter if irrigation is avail-able. Therefore, market demand and economic returns to farmers usually remain low. Without affecting crop duration for either rice crop, the short time lag (about 1 month) between spring and summer rice can be used, at the minimum, for a short season vegetable crop. Great market value but high production risks prevail during this period. Cool-temperature-tolerant varieties, early-maturing varieties, and use of older rice seedlings are means to extend the non-rice growing duration. Although the rice crop per se is not sacrificed, yields are being reduced. Vegetable crops can, however, be accommodated later in spring and earlier in summer or autumn, thereby avoiding the low-price winter season. There is discussion about 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. Complete replacement of rice in a year's cropping season is the most intensive diversification measure. Since land is still reverted periodically to rice to prevent build-up of harmful pests and to break the life-cycle of diseases, it is the frequency of rotation (usually one rice crop every 3–5 years) that determines the intensity of these systems. A broad mixture of the above-mentioned diversification schemes exists all over Asia.

Diversification over space

Cropping patterns in paddy fields are to a large extend governed by the reliability of water supply and availability of irrigation facilities. Within this framework, regional location (lowlands or highlands, distance from urban centres), and spatial arrangement within a farmer's land (division of area into rice and vegetable land, crop management in monocrop or intercrop systems) determine the level of diversification intensity: Although the acreage of non-irrigated agricultural land in some Asian countries is still high, it is of minor importance compared to already partially or fully irrigated area (Sjahri, 1975). Since fresh market vegetable production essentially depends on irrigation, even within the rainy season, it is pointless to concentrate on transformation of rainfed rice areas to vegetables. Constraints to vegetable production are numerous, but likely to increase with distance from input supply and market demand. These are mainly concentrated in urban centres. A large majority of these urban centres in Asia is located in the lowlands, with predominant traditional paddy rice production surrounding them. Besides availability of, and accessibility to production factors, it is the lack of transportation facilities and poor infrastructure in less developed countries which inhibits effective marketing of vegetables. This results in considerable losses with increasing distances from urban centres (Jansen et al., 19946), particularly from the high-lands. In more developed Asian countries, continuous increase in traffic volume impedes transportation of fresh-market vegetables. Partly as a result of infrastructural inadequacies, the highest level of diversification of rice land to vegetable production is obvious closest to cities in peri-urban, or even urban areas. Frequently non-resilient and easily perishable short growth-duration leafy vegetables are grown in intensive rotations or complex intercrop combinations on farms of very small sizes, replacing rice almost completely (Jansen et al., 1994a). Comparably, the greatest agricultural incomes are achieved in those most intensive vegetable farms. Above all, farmer's knowledge through specialization leads to higher productivity compared to farmers who only grow vegetables occasionally or on a small scale. With increasing distance from the urban centres, rice remains the predominant crop with year-round cultivation of vegetables only allocated to small parcels. Crops which store and transport well are more likely to be produced in these districts. Concerns for food security and aversion of production and marketing risks associated with upland vegetable production prevent farmers shifting away from rice (Pingali, 1992).

Transformation of the paddy rice field environment to upland vegetable production

Rice soils in highly populated tropical lowland areas are mostly alluvial, and low in organic matter. Long-term wet ploughing (puddling) has created a degraded, single-grained structure of surface soils on top of a hard plough pan in the compacted subsoil. Transition of this environment to a system suitable for cultivation of vegetables is not simply done by allowing the paddies to drain. Soil water and soil fertility are crucial factors for successful management of transformed rice fields.

Soil water management

Drainage and drying of a paddy field results in crack formation through shrinkage. This does not contribute to 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 drought damage in upland crops, 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 fields (Ishii, 1986).

Since vegetables put an extremely high demand on balanced water supply, raised beds are an essential measure to ensure good moisture management in the rainy season (Kleinhenz et al., 1995). Once soil pores are entirely filled with water following heavy rainfall, internal drainage is low in this environment due to small vertical hydraulic gradients when water tables are high. Under such conditions, horizontal drainage attains importance. Greater bed height provides horizontal drainage from the beds (source) to the deep furrows (sink). Minimum-tillage operations improve removal of excessive soil water. Better drainage make high beds more susceptible to drought in the dry season, or during prolonged periods without precipitation within the rainy season. This, however, can be overcome by irrigation, which is generally a necessity in vegetable production.

Soil fertility management

Rice is one of the few plants which absorbs ammonium-nitrogen (NH_4) more effectively than nitrate-nitrogen (NO_3^-). In contrast, roots of dichotyledonous plants absorb NO_3^- considerably more rapidly and even against concentration gradients (Scarsbrook, 1965). For the cultivation of vegetables it is, therefore, essential to modify the poorly aerated, reductive wetland environment to well-aerated, oxidized upland soil conditions. Studies on fertilizer use, crop residue, and green manure management as means to provide plant available (NO_3) nitrogen for vegetables have shown, however, that soil reductive conditions and its effects cannot be completely eliminated by 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 oxidized to NO_3^--N in these sites, which is then leached into underlying anaerobic soil layers to be possibly denitrified to N_2 and N_20, gases which are known to destroy the atmosphere's ozone-layer.

Clay minerals such as illite or vermiculite are able to immobilize ammonium through fixation (Drury and Beauchamp, 1991). Although ammonium is much less mobile in soil then nitrate, most of this fixation occurs in subsoils where clay content is higher. Losses of NH_4^+ by leaching can arise when the concentration of exchangeable ammonium exceeds the capacity of the fixing sites in clays to sorb the ammonium. Fixed (nonexchangeable) NH_4^+-pool and pools of exchangeable (microbially immobilized) NH_4^+ and water-soluble NH_4^+ were found to be in equilibrium state: 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 depleted to low levels by plant uptake, this fixed NH_4^+ can be released. This nitrogen may play a significant role in N nutrition of crops.

Besides its effect on macronutrients, low redox-potential in flooded rice soils also affects the state of micronutrients such as iron (Fe) and manganese (Mn). In the case of iron, insoluble ferric iron (Fe^{+}) is microbially reduced to plant available, but easily leachable ferrous iron (Fe^{2+}; Neue and Scharpenseel, 1984). High concentrations of reduced Fe and Mn in soluble 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.

If this wetland rice environment is converted to upland vegetable production (Fig. 1), organic matter that accumulates much more greatly under anaerobic conditions decomposes rapidly. Physical disturbance (tillage, weeding) can cause a stimulation of mineralization. As a result, organic matter is depleted and massive losses of (NO_3^--) N can occur through leaching after heavy rainfall, or when the field is shifted back to flooded rice production.

In our study of intensive year-round vegetable production at the Asian Vegetable Research and Development Center (AVRDC) in the tropical lowland of Taiwan, ferrous sulphate spray solutions had to be applied to seedlings of Chinese cabbage *(Brassica pekinensis* Lour. Rupr.) before planting. Carrots *(Daucus carota* L. ssp. *sativus* Hoffm. Arcang.) showed strong signs of Fe deficiency expressed as leaf chlorosis.

Soil contents of nitrate followed a seasonal pattern of accumulation of NO3- during the dry season and low contents during the rainy season. This seasonality appeared as a result of crop absorption and leaching governed by soil moisture which was low during the dry season and high during the rainy season (Fig. 2). However, effects of N availability were only secondary when water stress in vegetables through flooding inhibited efficient absorption of soil nitrogen (Kleinhenz et al., 1996).

Management of crop residues and green manure

Farming practices such as crop residue management and use of legumes as green manures, cover crops or living mulches can exert potentially detrimental effects in rice-based environments. Low redox potentials in rotated paddy fields create highly unsuitable conditions for incorporation of fresh organic materials. Externally added organic matter to flooded rice soils can accelerate soil reductive conditions through oxygen consumption of decomposing residues. If the soil oxygen is used up, these materials will start to decompose unaerobically. Anaerobic decomposition can lead to accumulation of phyto-toxic organic compounds, which are microbially converted to end-products of methane and carbon-dioxide (Watanabe, 1984b), accelerating the "green-house effect". Root injury to rice seedlings followed by stunted growth has been observed in waterlogged soils containing readily decomposable organic

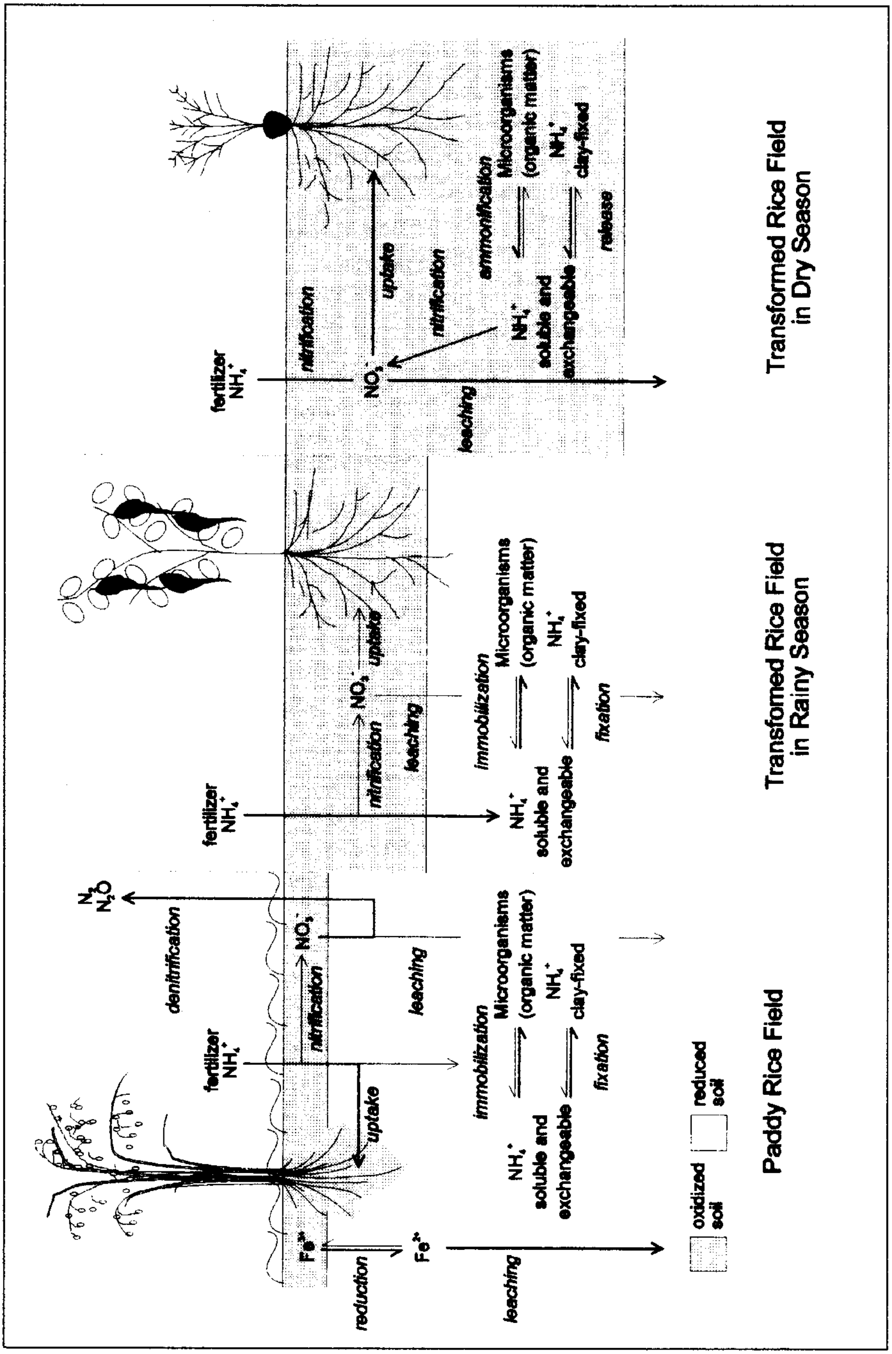

Fig. 1 – Soil-related processes in the transformation of paddy rice fields to vegetable production.

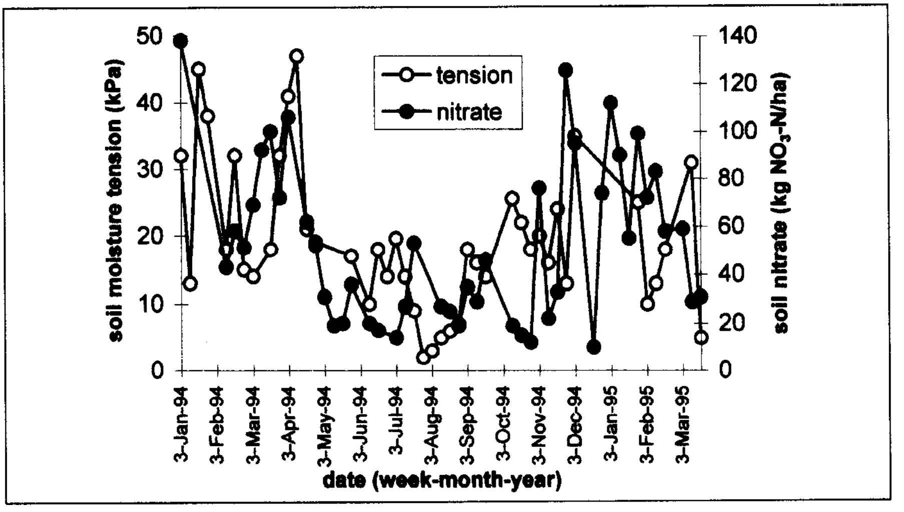

Fig. 2 — Mean weekly soil moisture tension at 15 cm soil depth and mean weekly soil nitrate content at 0 to 30 cm soil depth ***during 1994/95*** *at AVRDC in Shanhua, Taiwan.*

matter, and for subsequent crops other than rice if anaerobic conditions were not eliminated (Cannell and Lynch, 1984). Addition of organic material can further degrade wetland soils by lowering their 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 NO_3^--reduction through denitrification (Patrick and Wyatt, 1964).

In non-rice based cultivation systems, "soil-fatigue" is a well known phenomenon that can be attributed to the accumulation of potentially phyto-toxic volatile fatty acids (VFAs). These compounds appeared more severe and long-lasting with maturity of the incorporate in heavy, waterlogged and thus, poorly aerated soils, and particularly at cool temperatures. With crop residues, toxic effects of decomposing vegetable tissues on the same or different crop species are known. Phytotoxic substances may reach levels to kill seeds, transplanted seedlings, or even maturing plants. In our studies, incorporation of carrot crop residues in winter resulted in poor germination and emergence of vegetable soybean *(Glycine max. L.* Merr). Plant densities were reduced by 10 % through addition of 1.0 kg/m^2 residue material (Fig. 3) as were yields. Negative effects were evident even 9 months after incorporation of Chinese-cabbage residues, when yields of chili *(Capsicum annuum* L.) and carrot were significantly reduced (27 % and 21 % marketable yield per 1.0 kg/m^2 material; Fig. 4).

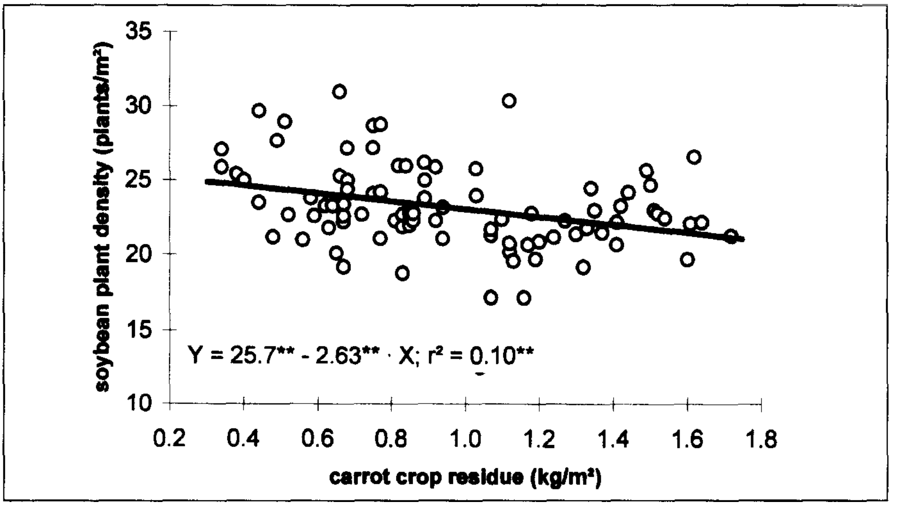

Fig. *3 – Influence of incorporated carrot crop residues on germination of succeeding vegetable soybean in March 1994 at AVRDC in Shanhua, Taiwan.*

Many efforts have been made to introduce green manure practices to tropical environments to increase N availability. The difference in N content (narrower C/N-ratio) between crop residues and green manures usually explains differences in their effect on soil 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 manure can result in the formation of phytotoxic organic acids with the same consequences as described above (Toussoun et al., 1986). To avoid damage from their decomposition products, winter green manure has to be incorporated several weeks before planting rice seedlings in China (Wen, 1984). In temporarily waterlogged soils, green manure can provide energy material to accelerate build-up of denitrifying microbe biomass (Patrick and Wyatt, 1964). Immobilization of soil nitrogen may be of significance even when high-nitrogen-containing material is incorporated (Stojanovic and Broadbent, 1956) and this might explain why C/N-ratios are not always suitable to predict decomposition rates. The effect of green manure applications on soil inorganic (NO_3^--) N in our study was determined by temperature: incorporation early in the season resulted in initial immobilization of soil nitrate and virtually no release (Fig. 5). As temperatures rose towards summer, immobilization was avoided, and the release phase was more pronounced. In less intensive cropping systems, green manure can be

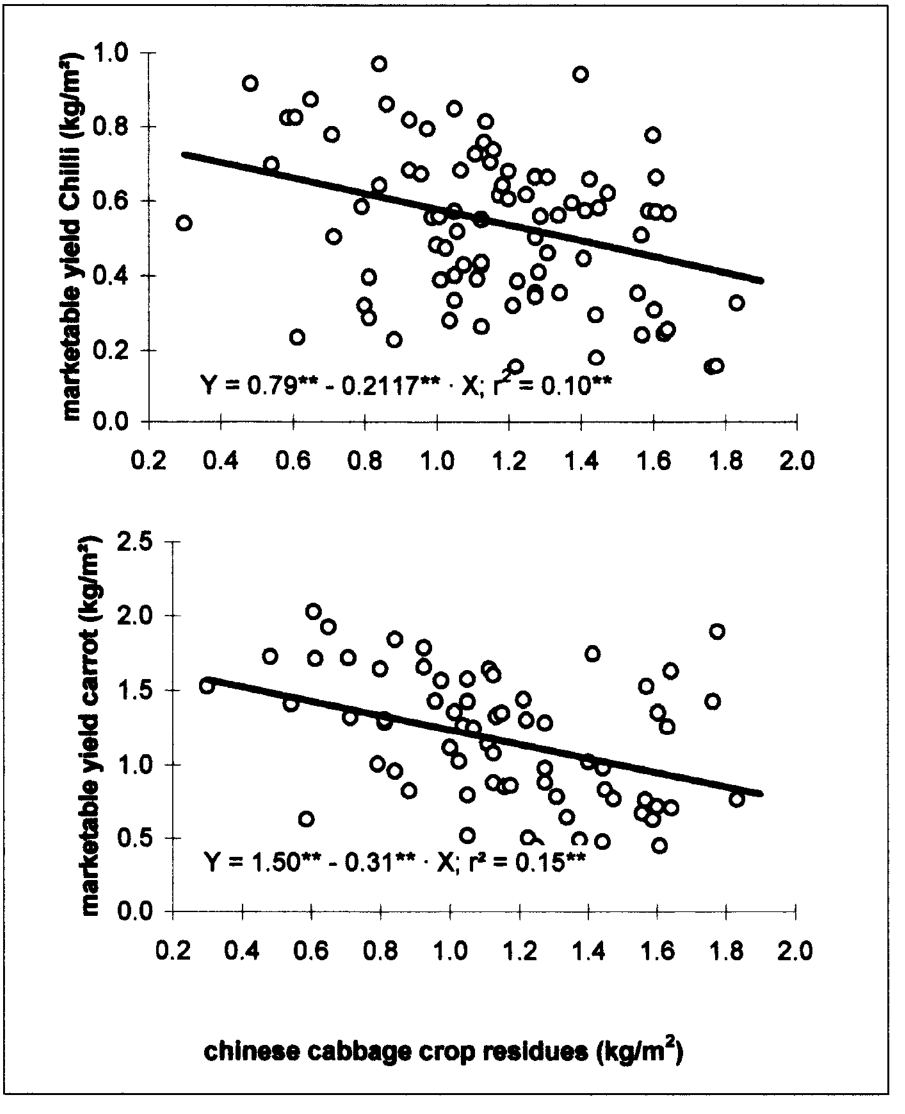

Fig. 4 — Influence of incorporated Chinese cabbage crop residues (harvest: June 1993) on marketable yield of succeeding crops of (left) chili (final harvest: November ***1993)*** *and (right) carrot (harvest: March 1994) at AVRDC in Shanhua, Taiwan.*

introduced as a tool to increase soil organic nitrogen. If grown and incorporated during the cooler winter, the crop will absorb mineralized soil nitrogen and more nitrogen will be immobilized when the crop is incorporated. This nitrogen can be recycled and become available to succeeding summer crops.

However, these crops should not be cultivated too soon after green-manure incorporation in order to avoid the detrimental effects mentioned. In intensive, continuous vegetable production, crop-residue and green-manuring practices are likely not to succeed.

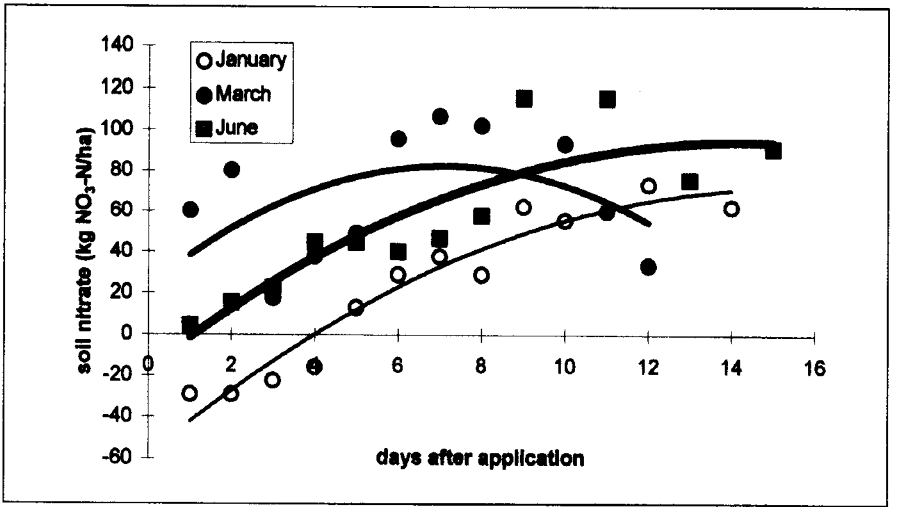

Fig. 5 — *Influence of legume green manure application (60 kg N/ha as Siratro; Macroptilium* ***atropurpureum*** *DC.) in combination with mineral N -fertilizer (60 kg N/ha as ammonium sulphate) on soil nitrate content in January, March, and June 1995 at AVRDC in Shanhua, Taiwan. Lines indicate second-order trends (thin line: January, medium thick line: March, thick line: June).*

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