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Volker Kleinhenz

Technologies for sustainable vegetable production in the tropical lowlands

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Technologies for sustainable vegetable production in the tropical lowlands

Volker Kleinhenz

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List of Abbreviations

%	percent
&	and
*****	significant at 5-percent level
****	significant at 1-percent level
° C	degree Centigrade
ANOVA	analysis of variance
AVRDC	Asian Vegetable Research and Development Center
C	carbon
ca.	circa
cm	centimeter
cm^3	cubic centimeter
cv.	cultivar
DM	Deutsche Mark
e.g.	for example
etc.	et cetera
FB	flat bed
Fe	iron
Fig.	figure
g	gram
h	hour
ha	hectare
HB	high bed
i.e.	id est
K	potassium
KCl	potassium chloride
kg	kilogram
kPa	kilo Pascal
LSD	least significant difference
m	meter

m^2	square meter
MISMT	mean integrated soil moisture tension
mm	millimeter
Mn	manganese
N	nitrogen
n	number of observations
n.s.	not significant
N_2	nitrous gas
N_2O	nitrous oxide
NH_4	ammonium
N_{min}	soil mineralized nitrogen
NO_3	nitrate
NT$	New Taiwan Dollar
∅	mean
P	phosphorus
pH	soil reaction
ppm	parts per million
r^2	level of determination
SE	standard error
t	ton
US$	United States Dollar
VFA	volatile fatty acid
vs.	versus
WAS	weeks after sowing
WAT	weeks after transplanting

I General Introduction

1 Future Food Demand and Supply

Secure food supply is a basis for economic, social and cultural development, and for political stability. To match future food demand, food production must be dramatically increased. It is projected that the world population will increase to 8.2 billion people by 2025, a 53-percent increase from 1990 (VON UEXKÜLL, 1995). However, populations in many tropical regions such as sub-Saharan Africa and South Asia grow at a markedly higher rate compared to the overall population. More than 50 percent of the future world population is predicted to live in Asian countries.

The supply of the people with carbohydrates has improved worldwide in the last decades. Many countries in Asia have attained self-sufficiency in rice production and some have changed from net-importers to net-exporters of rice. However, numerous micro-nutrients are still deficient: an estimated two billion people are suffering from diseases at least partially caused by deficiencies of one or more micro-nutrients, particularly in Africa and South Asia (CHEN, 1995).

Expansion of arable area for food supply is not indefinite. One other way is by intensification of production on already existing agricultural land. In the past, marginal land such as peat areas were regarded suitable for reclamation through *land clearing* (ISMUNADJI & SOEPARDI, 1984). Presently, those potentially cultivable areas are already used up, or were found unsuitable for crop production for environmental reasons. *Rehabilitation of degraded land* (deforestated rainforests, sloping lands, and some highland areas) may offer some opportunities to expand agricultural land (HÄRDTER *et al.* 1995; FAIRHURST, 1995), but such attempts require initially large amounts of inputs that small-scale farmers cannot afford (VON UEXKÜLL, 1995). In Asia, not only a majority of the population lives in the tropical lowlands, but also the most productive agricultural areas are concentrated in those zones. *Intensification of production on existing agricultural land* may remain a main vehicle for future increase in food output.

The tropical lowlands in Asia have traditionally been used for production of rice

and as the first cultivated crop ca. 5,000 years ago, it has supported dense populations for long times (BRADFIELD, 1972). 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, steady declines in rice profitability have since long created demand for a more diversified agricultural production. Narrowing margins of rice profitability and reduced income of rice farmers have several reasons (PINGALI, 1992):

- Despite governmental protection of domestic markets and subsidies for some production factors (e.g. fertilizers), rice prices are continually declining since 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 decreased by ca. 50 percent, whereas vegetable consumption almost doubled. Less demand, but advanced cultivation techniques have resulted in expensive rice overproduction.

2 Vegetable Production in the Tropics

Vegetables are a major source of essential nutritious substances such as carotene and micro-nutrients (BELLIN & LEITZMANN, 1995). Increased consumption of these nutrients has been highlighted as a priority social development objective in some tropical countries whose vegetable availability is below the recommended intake (UNDP, 1991; ALI *et al.* 1994).

Many commercially grown vegetable species in the tropics are of temperate type. *Tropical highlands* are, therefore, usually considered more agri-ecologically suitable

for vegetable production, particularly in view of pest incidence and temperature. However, a number of constraints limit the prospect of expanding vegetable cultivation areas in tropical highlands: poor infrastructure in less developed countries limits accessibility to production factors (e.g. seeds, fertilizers, and pesticides around Kathmandu; JANSEN *et al.* 1996*a*) and inhibits effective marketing of the produce. This results in considerable transportation losses with increasing distances from the highly populated urban centers which are typically located in the lowlands (e.g. Dalat highlands, 300 kilometers from Ho Chi Minh City in Vietnam; JANSEN *et al.* 1996*b*). In more developed countries, continuous increase in traffic volume impedes transportation of fresh-market vegetables. Use of sloping highlands for crop production is frequently associated with the ecological consequences of deforestation, soil erosion, and soil degradation. Examples include Northern Thailand and the Cameron highlands in Malaysia (AVRDC, 1994; MIDMORE *et al.* 1996).

Aside from *specialized lowland production areas* distant from urban centers (e.g. Tien Giang; 70 kilometers from Ho Chi Minh City in Vietnam), vegetable production in *peri-urban lowland zones* has recently been proclaimed as a major way to provide produce for the large numbers of people living in and around big cities in the tropics (RICHTER *et al.* 1995). Urban populations grow at a markedly higher rate compared to the overall population in many tropical countries. The pro-urban shift is expected to make 80 percent of the population to live in urban areas in the future (SMIT, 1995), stressing the need for increasing vegetable production in this ecological zone.

3 Vegetable Production in Tropical Lowlands

3.1 Vegetable Cropping Systems

Vegetables are frequently a component of traditional cropping systems in tropical lowlands. In Asia, cropping systems are since ages centered around cultivation of rice. Rice is frequently grown 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 fit in those systems at different levels of intensity over time and space. They can *complement*, *diversify*, or *replace* rice production. It has frequently been shown that the intensity (e.g. requirement for capital and labor, returns) of such systems increases with increasing degree of

complementation of rice with vegetables (HSIEH & LIU, 1986):

(1) Probably the most common but least intensive cropping system of rice and vegetables is to cultivate one or more vegetable catch crops between harvest of one year's second (summer) rice and transplanting of the next year's (spring) crop. Vegetables can be grown with little difficulty during the dry fallow period, particularly in the mild, subtropical winter if irrigation is available. Since market supply is largely sufficient in this season, market price and economic returns to farmers usually remain low.

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

(3) 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 avoid the low-price winter season.

(4) 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 also 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 year's cropping season is the most consequent measure. Since land is still reverted periodically to rice to prevent build-up of harmful pests and diseases in vegetables, 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 schemes exists all over Asia.

Cropping systems are to a large extent governed by the reliability of water supply and availability of *irrigation* facilities. In this framework, the *regional location* (distance from urban centers) mainly determines the spatial arrangement in a farmer's land and the level of intensity of vegetable production:

(1) Although the acreage of non-irrigated agricultural land in some Asian coun-

tries 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 in the rainy season, it is pointless to concentrate on utilization of rainfed areas for vegetable production (MAHMUD *et al*. 1994).

(2) The spatial distribution of land-use forms around cities has been recognized for a long time. The concept of von Thünen's "rings" (VON THÜNEN, 1826) is probably the most prominent. One of the key issues in this concept is that the most perishable of primary products are produced more closely to markets and consumers. There are similarities between von Thünen's theory and existing vegetable production systems around big cities in the tropics. Because of infrastructural inadequacies, vegetables are most intensively produced close to the cities. Frequently non-resilient and easily perishable early maturing leafy vegetables are grown in intensive rotations or complex intercrop combinations on farms of very small sizes, replacing rice almost completely (JANSEN *et al.* 1996*a*). With increasing distance from the urban centers, field crops like rice remain predominant with year-round cultivation of vegetables only allocated to small parcels. Vegetables 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 vegetable production prevent farmers shifting away from rice (PINGALI, 1992).

3.2 Production Constraints and Solutions

3.2.1 Soil Water

The deficit in average vegetable availability in many tropical countries depends largely on the pronounced seasonality of vegetable supply, which is sufficient during the dry season, but not during the rainy season. In Ho Chi Minh City, vegetable consumption of the population is particularly low (ALI *et al.* 1994). During the rainy season in September, virtually no vegetables are harvested in the adjacent lowlands and even highland production cannot compensate for this deficit. Besides greater plant pathogen incidence and intolerance to high temperature, it is particularly *water stress* resulting from excessive soil water which limits production during the wet periods of the year.

Crop breeding programs have led to significant yield improvements in several vegetable species under high temperature conditions. Some genetic tolerance to waterlogging has been identified (KUO *et al.* 1982) and biotechnology may offer pathways to induce flood-tolerance in vegetables (DENNIS *et al.* 1993), but, until proven successful, *crop management techniques* will be the only short term way for increasing vegetable production during the rainy season.

Several low cost and low external input practices have been developed to overcome flooding-stress in vegetables. Grafting and use of fruit-set hormones are two practices to extend growing tomato as one of the most important vegetable crops under hot-wet tropical summer conditions (MIDMORE *et al.* 1994; MIDMORE *et al.* 1997). Quick and inexpensive *grafting* procedures of tomato onto tomato or eggplant rootstocks tolerant to waterlogging has resulted in significant yield increases over several years. Cheaply available *fruit-set hormones* (tomato-tone) improved yield over several years and was particularly effective during heavy rainy periods (AVRDC, 1995). Protection of summer vegetables from the direct impact of heavy rain by *rain-shelters* made from cheap, locally available materials (MIDMORE *et al.* 1992) has been shown effective in some tropical environments (Malaysia, JAAFAR *et al.* 1992; Taiwan, CHEN & CHEN, 1991).

Another way for relaxing constraints to vegetable production in tropical lowlands is the use of appropriate drainage methods which facilitate the removal of unwanted excess water during high-rainfall periods. Drainage can be attained by *deep plowing*, *underground drainage*, and *reshaping of the land* (MIRANDA & PANABOKKE, 1987). *Simple raised beds* (20 to 25-cm high) can be prepared with minimum costs and are a common cultivation system for vegetables in the dry-season fallow period between rice. Research has focused on construction of *temporary high beds* (up to 45 cm) for a single crop during the rainy season. The potential benefits of this practice have been shown repeatedly (AVRDC, 1980; AVRDC, 1982; AVRDC, 1993; AVRDC, 1995). *Permanent high beds* (50 cm or higher) were known to exist in ancient times and are presently used in localized areas in the lowland tropics.

3.2.2 Soil Fertility

There is increasing concern that fertilizers in vegetable production threaten public health by contaminating the produce with high levels of pollutants and polluting the environment. However, fertilizers are an integral part of commercial vegetable pro-

duction. Controlled use of fertilizers maintains soil fertility for safeguarding and increasing yields. It is the over-use of fertilizers and especially N-fertilizers that is often associated with environmental pollution and degradation of agricultural soils. This is particularly true in intensive vegetable production in the tropics (HUANG *et al.* 1989).

The concerns for the negative consequences of over-fertilization with N such as high levels of nitrates in vegetables and leaching of nitrates to the groundwater has led to the demand for the development of innovative N-management strategies. Those are directed towards fine-tuning the amount of N-fertilizer to better synchronize soil-N availability with plant requirements.

The N_{min}-*method* (SCHARPF & WEHRMANN, 1975; WEHRMANN & SCHARPF, 1986) can be one tool to minimize N-fertilizer consumption and thereby prevent environmental pollution by excessive fertilizer use. *Analysis of plant index-tissues* was advocated for evaluation of crop nutrition as a guide to appropriate fertilization (e.g. GOODALL & GREGORY, 1947). Use of *crop residues* and *green manure* is considered an integral part of vegetable production to (1) conserve fossil oil, (2) reduce ground water pollution, (3) overcome the risk of high nitrate levels in vegetables, and (4) conserve soil resources (KELLY, 1990).

3.3 Economy of Management Technologies

Although socioeconomic studies (e.g. JANSEN *et al.* 1996*b*) have covered the economy of vegetable farms in the tropics, only few analyses are available which evaluate the economic viability of improved crop and field-management techniques for vegetable production in tropical lowlands (e.g. MIDMORE *et al.* 1997). Economic analyses covering decision-making of farmers are complex and cannot completely be solved by mathematical approaches (PANNEL, 1995). However, capital-budgeting procedures (e.g. EHUI *et al.* 1990) may be useful for determination of profitability of field/crop management technologies.

4 General Objectives of this Study

The overall objective of this study was to investigate cultivation techniques for sustainable vegetable production in the lowland tropics. Introduction of suitable combinations of economically viable agronomic practices are necessary to (1) increase vegetable production particularly during the tropical rainy season when vegetable

supply and consumption are largely deficient, to (2) maintain land productivity, and to (3) minimize environmental damage.

To fulfill the overall objective, the following technologies were tested for their potential to improve vegetable production in tropical lowlands:

- Evaluating the indigenous method of *permanent high beds* and adapting the system to modern agricultural technology and for commercial economic application
- Testing a modified N_{min}-method ("*N_{min}-reduced method*") for its' potential to maintain maximum vegetable yields but reduce environmental damage
- Developing an *integrated analysis of soil and plant nitrogen* to determine its' value for appropriate, environmentally sound fertilization
- Testing technologies of *green-manure management* and *crop-residue management* as tools for maintaining land productivity

It was evaluated how these technologies affect vegetable production through their effects on agronomic and economic factors including: (1) soil water, (2) soil nitrogen, (3) plant nitrogen, (4) land productivity, and (5) farm profitability.

Specific strategies in the approaches are outlined in Chapter III.

II Experimental Layout

1 Site

All experiments and analyses were conducted at the experimental farm of the Asian Vegetable Research and Development Center (AVRDC). AVRDC is located in the alluvial lowland plain of southwestern Taiwan near the cities of Tainan and Shanhua at 120° E longitude and 23° N latitude at a mean elevation of 8 meters above sea level.

Taiwan's seasonally wet/dry *weather* is dominated by the monsoon winds resulting from a shift of pressure centers over Central Asia. In winter, the northeast winds pick up moisture from the East China Sea. Most of this moisture is precipitated in the northern and central highlands of Taiwan and leaves the southwestern part in a rain shadow (RILEY, 1978). In summer, the southwestern monsoons bring abundant moisture and rainfall to southern Taiwan. Evaporation exceeds precipitation most significantly at the beginning and at the end of the dry season (October and March) when sunshine intensity is high and clouds are rare (Fig. II-1). Accumulated rainfall usually

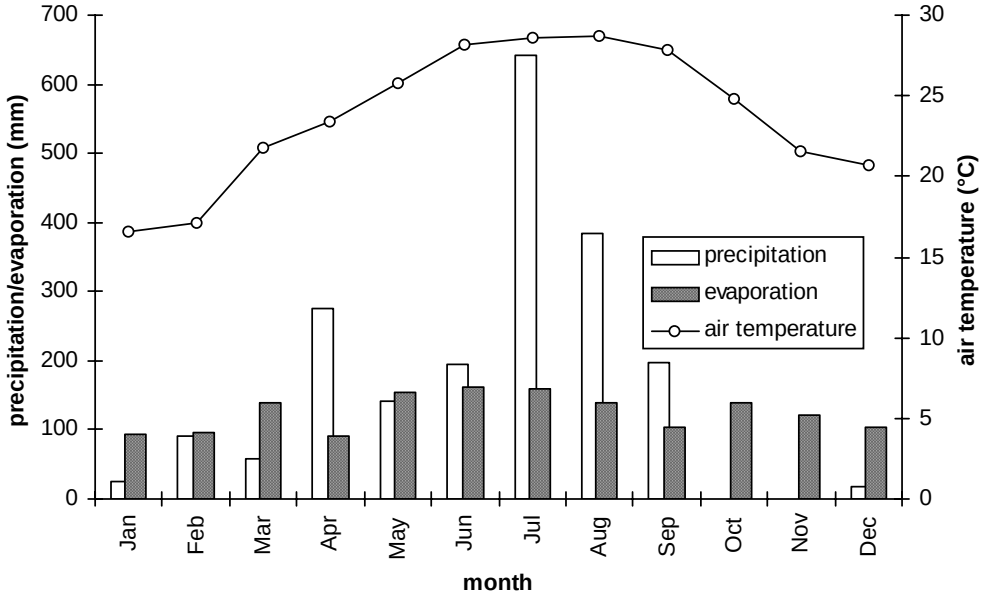

Fig. II-1 ***Mean cumulative monthly precipitation and evaporation, and mean monthly air temperature at AVRDC 1992 to 1995***

approaches 2,000 mm annually of which more than eighty percent occurs between the rainy-season months of April through September. Mean daily air temperature during this period is almost 30° C, but maximum temperatures can reach more than 35° C. The annual mean relative humidity is above 80 percent with only small variations.

Soil at the experimental site consists of the Take series and was derived from a calcareous alluvial parent material. The soil type is sandy loam (18 % clay containing illite and vermiculite, 27 % silt, 55 % sand) with low total-N content (< 0.5 %) and a pH around 7.

2 Field Experiments

2.1 Cultivation Systems

To study the effects of vegetable cultivation technologies on soil-related growth factors and productivity of vegetables and aquatic crops in year-round intensive production, experiments were conducted on field plot 47 of the AVRDC farm. The whole experimental area of 2,000 m^2 was divided into four sections: (1) vegetable production area on traditional flat beds (1.5-m wide and 20 to 25-cm high), and (2) on permanent high beds (50-cm high) with varying widths (in 1992: 2.00 m, 2.75 m, and 3.50 m; from 1993 to 1995: 2.00 m and 3.00 m). Aquatic crops were cultivated on (3) one control plot (240 m^2) and (4) in 2.00-m-wide furrows between the high beds. All plots were 40 m long. Flat beds for vegetables and the control plot for aquatic crops, and high beds with furrows in-between were regarded separate units. Field management logistics restricted the flat-bed treatments to a location adjacent to that of high beds.

Flat-bed and high-bed cultivation area was tilled with a tractor-driven rotovator before onset of each vegetable crop. Flat beds were mechanically built before sowing or transplanting each crop and high beds were permanently prepared by hand in spring 1992, reconstructed in spring 1993, and rebuilt in winter 1993. Production area for aquatic crops was tilled twice before transplanting crops: in dry condition and after flooding in wet condition (“puddling”).

2.2 Crops and Crop Management

To develop agronomically and economically viable crop sequences for vegetables and aquatic crops year-round, several crop species were tested. It was emphasized to produce vegetables during the rainy season which are low in supply but fetch high market prices in that season. Species for the dry season were chosen according to crop rotation logistics. During 1992 four *vegetable varieties* were cultivated at least partly under rainy season conditions:

- Chinese cabbage (*Brassica pekinensis* Lour. Rupr.; cv. "ASVEG No. 1", AVRDC)
- common cabbage (*Brassica oleracea* L. cv. *capitata* var. *capitata*; cv. "Ping Huh", Known You Seed Co.)
- tomato (*Lycopersicon* Mill. *lycopersicum* (L.); cv. "CL 5915-93D4-1-0-3", AVRDC)
- chili (*Capsicum annuum* L.; cv. "Hot Beauty", Known You Seed Co.).

From 1993 to 1995, the vegetable crop sequence was changed to:

- Chinese cabbage
- chili
- carrot (*Daucus carota* L.; cv. "Red Judy", Known You Seed Co. (1994) and cv. "Parano", Nunhems (1995))
- vegetable soybean (*Glycine max*. (L.) Merr; cv. "AGS 292", AVRDC).

Chinese cabbage and chili were cultivated during the summer rainy season, and carrot and vegetable soybean during the dry season. With this crop sequence four vegetables of different botanical families and growth characteristics were chosen. *Aquatic crops* in the control plot and the furrows between high beds were rice (*Oryza sativa* L.) and water-taro (*Colocasia esculenta* (L.) Schott). Details of the crop-rotation pattern are presented in Fig. II-2.

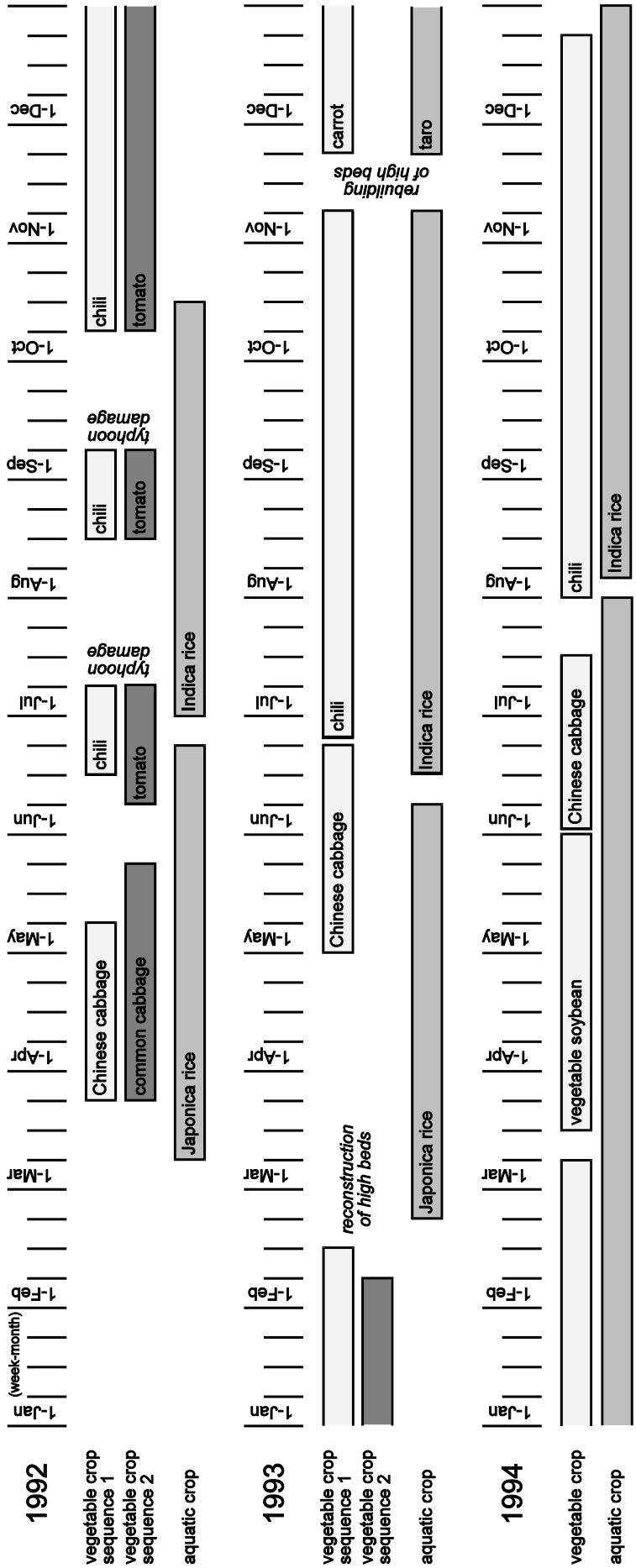

Fig. II-2 *Crop sequence of vegetables and aquatic crops in the field experiments 1992 to 1995*

Chinese cabbage and chili were pre-nursed in a glasshouse and transplanted according to a *plant-arrangement* scheme with distinct crop-row distances always measured from the edge of a bed:

1992:

- flat bed: 40 cm
- 2.00-m-wide high bed: 40 cm, 80 cm
- 2.75-m-wide high bed: 40 cm, 80 cm
- 3.50-m-wide high bed: 40 cm, 80 cm

1993-95:

- flat bed: 40 cm
- 2.00-m-wide high bed: 40 cm, 80 cm
- 3.00-m-wide high bed: 40 cm, 80 cm, 120 cm

Distances between plants in crop rows were:

1992:

- flat bed: 40 cm
- 2.00-m-wide high bed: 33 cm
- 2.75-m-wide high bed: 38 cm
- 3.50-m-wide high bed: 40 cm

1993:

- flat bed: 40 cm
- 2.00-m-wide high bed: 60 cm
- 3.00-m-wide high bed: 60 cm

1994-95:

- flat bed: 40 cm
- 2.00-m-wide high bed: 40 cm
- 3.00-m-wide high bed: 40 cm

Inter-row distances of aquatic crops were 33 cm (rice) and 66 cm (water-taro). Carrot and vegetable soybean were sown using a hand sowing-machine with the same crop row distances (paired rows for carrot) from the edge of beds. Inter-row distances were approximately 5 cm (carrot) and 10 cm (vegetable soybean). Details of cultivation systems and plant arrangements are presented in Fig. II-3.

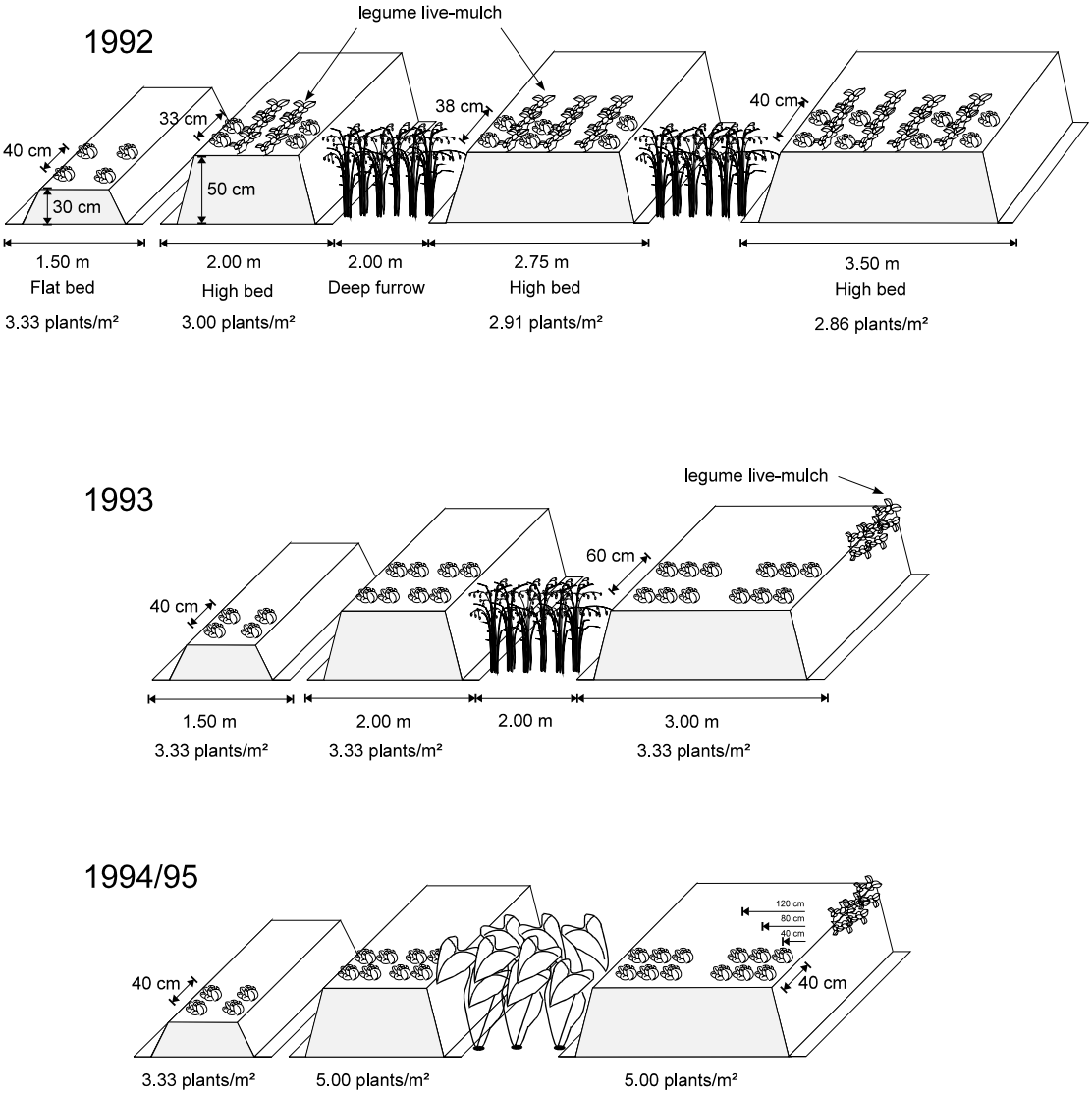

Fig. II-3 ***Dimensions for cultivation systems and arrangements of vegetables, aquatic crops, and legume live mulch in the field experiments 1992 to 1995 (details of the live-mulch treatment are discussed in Chapter III)***

Nitrogen was applied as ammonium sulfate (21 % N), phosphorus as calcium superphophate (18 % P_2O_5), and potassium as potassium chloride (60 % K_2O). Standard rates for the various vegetables followed AVRDC recommendations (Tab. II-1).

Table II-1 ***Schedules and standard application rates of fertilizers for vegetables and aquatic crops in the field experiments from 1992 to 1995***

Vegetable…	Chinese cabbage				Chili					Carrot				Vegetable soybean			
WAS/WAT [a]…	0	2	3	Total	0	4	8	12	Total	0	5	9	Total	0	2	4	Total
N (kg/ha)	60	30	30	120	50	50	50	50	200	60	60	60	180	20	20	20	60
P (kg/ha)	20	0	0	20	60	20	20	20	120	90	0	0	90	60	0	0	60
K (kg/ha)	60	20	20	60	60	20	20	20	120	150	0	0	150	60	0	0	60

Aquatic crop…	Indica rice				Japonica rice				Water-taro			
WAS/WAT…	0	2	10	Total	0	3	12	Total	4	8	12	Total
N (kg/ha)	45	45	60	150	60	30	30	120	46	56	56	168
P (kg/ha)	50	0	0	50	50	0	0	50	48	48	48	144
K (kg/ha)	12	12	6	30	12	12	6	30	60	60	60	180

[a] Weeks after sowing/weeks after transplanting

Fertilizers were mixed and tilled into the soil for basal applications or applied to the soil surface for each side dressing.

Vegetable crops were *irrigated* overhead with perforated pipes. The aquatic area was regularly flooded to keep the water at a height of a few centimeters. *Weeds* in aquatic crops were controlled with herbicides, vegetable plots were regularly hand-weeded. *Plant protection* followed current AVRDC recommendations for the various crops.

Vegetable *yields* were recorded from individual rows in each plot. Data from the border between plots (flat beds: 2 m, high beds: 1 m) was not used. Pods of vegetable soybean and fruit of chili were hand-picked. Pods of soybean and peppers of chili were regarded marketable when there were no signs of damage caused by pests or diseases. Marketable yield of Chinese cabbage was determined as weight of un-damaged heads without wrapper leaf and stump. Carrot yield was recorded as weight of roots without cracks. Yield of rice was recorded as polished dry grain weight and yield of water-taro as fresh-weight of main corms.

2.3 Experimental Design and Data Analysis

In 1992, the experiments followed a randomized split-split-plot design including crop sequence with two levels (Chinese cabbage — chili — tomato and common cabbage — tomato — chili) as the main-plot factor. High-bed width with three levels (2.00 m, 2.75 m, and 3.00 m) was the sub-plot factor, and legume live-mulch with five levels (four legume species and no live mulch) the sub-sub-plot factor.

From 1993 to 1995, the experimental design was rearranged so that high-bed width with two levels (2.0 m and 3.0 m) was the main-plot factor, legume live-mulch with five levels (four legume species and no live mulch) the sub-plot factor, and N-fertilizer rate with two levels (standard N-rate and "N_{min}-reduced" rate) the sub-sub-plot factor. Only the N-fertilizer treatments were randomized on flat beds. All treatments were replicated four times (Fig. II-4). The fertilizer treatment and the live-mulch treatment will be discussed in Chapter III.

Yield data from high beds were analyzed with a split-split-block ANOVA (four replications). Means of levels of main factors (1992: crop sequence, high bed width, and legume live-mulch; 1993 to 1995: high-bed width, legume live-mulch, N-ferti-

lizer rate) were separated with the LSD-test. Comparison of cultivation systems (flat beds vs. high beds) and legume live-mulch (no live-mulch vs. all other live-mulch treatments) was done with orthogonal contrasts. ANOVA, regressions, and standard errors were calculated with SAS (SAS INSTITUTE INC., 1989).

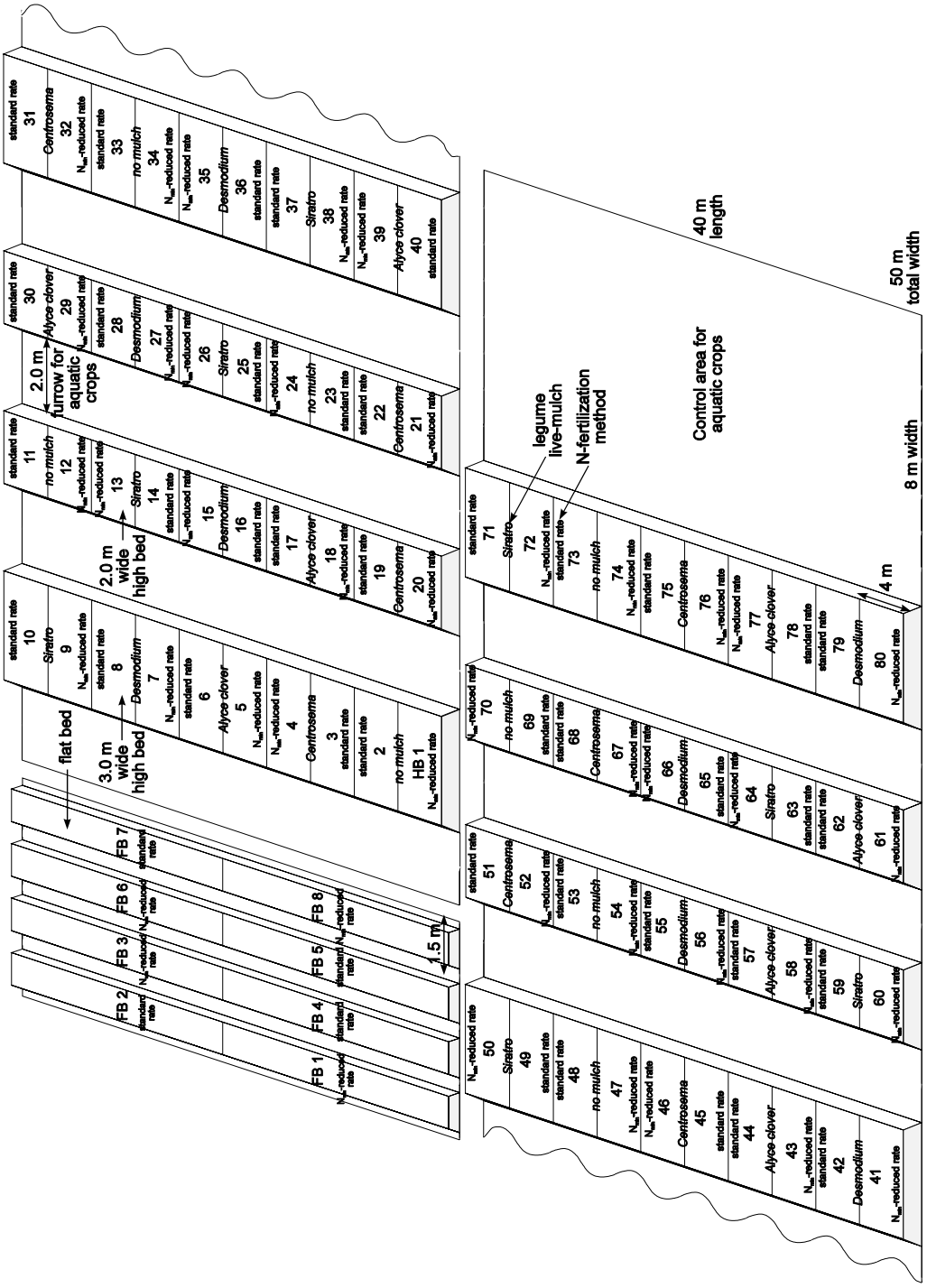

Fig. II-4 *Layout and randomization of experimental treatments in the field experiments 1993 to 1995 (details of the treatments N-fertilization and legume live-mulch are discussed in Chapter III)*

III Effects of Crop Management Technologies on Vegetable Production

A Effects of Permanent High Beds on Vegetable Production — Soil Water

1 Introduction

1.1 Flooding Damage in Vegetables

Soil flooding limits oxygen supply to plant roots and constrains rainy-season vegetable production. Flooding injury in plants occurs when soil water displaces the soil air, and the slow diffusion of oxygen in water drastically reduces the supply to the roots (KRAMER, 1983). Under absence of oxygen, accumulation of ethylene and carbon-dioxide in the root zone induces toxic effects. *Water stress* in plants after prolonged flooding originates from increased root resistance to water absorption. The plant's hormone system is disturbed as formation of cytokinin in roots and its' translocation to shoots is inhibited. Downward transport of auxin from shoots below the water line is hemmed. Accumulation of auxin shortly above the anaerobic soil leads to formation of adventitious roots which take over the function of the dying deeper roots. Anaerobic respiration in the place of glycolysis in flooded plants produces only incompletely oxidized, presumably injurious compounds such as ethanol and organic acids, and only a small fraction of energy is recovered (KRAMER, 1983).

Chinese cabbage (*Brassica pekinensis* (Lour.) Rupr.) and chili (*Capsicum annuum* L.) are two of the vegetables most sensitive to soil inundation under high-temperature conditions. Flooding in Chinese cabbage impedes the active processes of its root system, preventing soil-water uptake and, thus, reducing plant turgidity. Flood damage may only cause a reduction in plant growth, but can also lead to complete destruction of the root system (AVRDC, 1986). However, an extensive root system is a

prerequisite for sufficient uptake of soil water and mineral nutrients to facilitate photosynthesis (YINGJAJAVAL, 1990). Root development is important in avoiding the non-parasitic physiological disorder of "tipburn" (necrosis of leaf margins) caused by calcium deficiency. Restricted root growth through flooding impairs root uptake and translocation of calcium in tissues from the older, outer leaves towards the younger, inner leaves. Since the inner leaves have a low potential for transpiration, a reduction in soil-water uptake through low root mass makes them more susceptible to deficiency of the immobile nutrient and subsequent development of tipburn (ALONI, 1986). Flooding in chili induces decline in photosynthesis, and leads to reduction in leaf area, plant weight, and dry-matter accumulation. This can be attributed to a permanent damage of the carbon-fixing system (AVRDC, 1993). Formation of lysigenous aerenchyma in the basal stem which facilitates oxygen transport from the aerial plant parts to the anoxic root system, and adventitious root formation close to the aerobic soil surface are plant responses in chili under soil flooded conditions (AVRDC, 1990).

1.2 Relevance for Vegetable Production in Tropical Lowlands

In spite of the highly developed vegetable industry in Taiwan, the strong seasonality in market supply and prices, and in consumption of vegetables could not be eliminated. Some of the reasons for the pronounced deficit in vegetable production during the rainy season are soil water conditions, the properties of soils in tropical lowlands, and high temperatures.

During the rainy season, deficient and excessive moisture conditions induce water stress in vegetables and can proceed in close alternation (MIDMORE *et al.* 1992). This is due to quick successions of heavy rainfall periods and times of sunny weather, and due to soil properties. Soils in tropical lowland areas are mostly alluvial, and low in organic matter. Long-term wet plowing (puddling) in rice cultivation has created a degraded, single-grained structure of surface soils on top of a hard plow pan in the compacted subsoil. Drainage and drying of these soils 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 susceptible vegetable 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 (ISHII, 1986).

Crop damage by flooding is usually aggravated by temperature. This aspect cannot be underestimated: flooding under high temperature conditions is considerably more injurious to the crop as under cooler temperature.

1.3 Permanent High Bed Technology for Water Management

Cultivation on permanently prepared high beds is one option to overcome flooding stress in vegetables during the rainy season. Historically, their use probably dates back 4,000 years in Central and Southern America. “Raised fields” were permanent horticultural platforms lifted above the natural terrain with associated canals to control water levels around rooting layer and planting surface (TURNER & HARRISON, 1981). These prehistoric agricultural systems were located in the margins of lakes, rivers and swamps, or in savannas subject to seasonal flooding and waterlogging for several months of a year. They can be divided into two categories (DENEVAN, 1970): (1) “chinampas” in the temperate highland of the Valley of Mexico played a major role in feeding the Aztec capital of Tentochitlan. They were allocated in lakes and are partly still in use to supply modern Mexico City with vegetables and other food crops (WERNER, 1994). (2) Remnants of pre-Hispanic “ridged fields” in South America were found in lowland tropical savannas, and terrain subject to seasonal flooding (“Mayan lowlands”).

Although developed independently by different indigenous cultures, these systems have some unique features. A hierarchical system of canals of different width extended through raised fields that varied in shape and size. Besides irrigating the raised fields, the waterways and canals presumably served as sources of water for drinking, bathing, wetland crop production, fish culture, and transportation. The plateaus were prepared and maintained by piling up soil, aquatic plants, and animal manure in pre-

cise layers (REDCLIFT, 1987). Cultural practices which helped sustain yields for long times were the harvest of aquatic vegetation from the canals and shoveling of canal sediments onto the raised fields during the dry season (CARNEY *et al.* 1993). Nutrients were kept in the agricultural system to maintain soil fertility and reduce pollution of downstream water. Off-season planting of grain legumes as green manure on the raised beds was practiced to enhance soil organic matter (BOUCHER *et al.* 1983).

It is assumed that agriculture in Central and Southern America developed first on drylands and subsequently included wetlands as population pressure increased (TURNER & HARRISON, 1981). Management of soil water and soil fertility promoted conditions suitable for intensive cultivation throughout the year which was required to support large, dense populations (MATHENY, 1976). These time and labor-intensive practices did not justify lengthy fallow periods and, at the same time, allowed shortening fallow periods by maintaining land productivity (TURNER, 1976). In recent times, rehabilitation of raised fields and transfer of know-how to other sites for modern agricultural use was proposed (WERNER, 1994; ALTIERI, 1996).

At present, certain permanent high-bed agricultural systems are spanning Asia and the Pacific from Polynesia to India. In Papua New Guinea, efforts have been made to restore an indigenous agricultural system where tropical food crops such as taro, cassava, sweet potato, maize, and yam were grown on long, narrow "island beds" (VASEY, 1983). KIRCH (1978) described a traditional cultivation system of permanent "garden-islands" in the low-lying coastal areas on Uvea (Western Polynesia). The swampy area was modified to form intensive drainage networks. They served as sources of water to irrigate and drain the 0.75 to 1.00-m high raised beds and provided clean water for drinking and bathing. Population and social pressure on agricultural production necessitated the intensive drainage systems which are approximately 2,000 years old.

The presumably most intensive high-bed systems for vegetable production can be found in Southern China and Taiwan. Following the crop-distribution policy of the government in mainland China, vegetable production is concentrated in "permanent"

production areas close to the cities (HARWOOD & PLUCKNETT, 1981). In the heavy-rainfall areas of Southern China, vegetables are usually planted on 0.5 to 1.0-m wide and 50 to 70-cm high raised beds (CHANDLER, 1981). The height of the beds depends on the height of the water table. During the humid summer season, soil and nutrients erode into the low ditches of the system. Returning this mud during the dry season raises the height of the bed and helps to maintain soil fertility (LUO & LIN, 1991). Every three to five years the land is leveled for one rice crop to protect against outbreaks of pests and diseases. Pumping stations supply irrigation water during dry periods and remove excess water in periods of heavy rainfall (CHANDLER, 1981). To maximize year-round vegetable production for the dense population, sometimes more than a dozen crops are grown in intensive intercrop combinations in one field during a year. Water crops such as rice and taro are frequently cultivated on the edges of the raised beds or in the low ditches. Production of fish and edible snails is employed in fish pond-dike systems (LUO & LIN, 1991) as is cultivation of water plants in the ditches to recover nutrients lost by leaching or surface-washing from the beds (GUO & BRADSHAW, 1993). Crops are intensively fertilized with various organic materials (PLUCKNETT *et al.* 1981).

The layout of the vegetable cultivation system in lowland Central Taiwan (Changhua county) principally corresponds to the system in Southern mainland China (SU, 1981; 1986): vegetables are cultivated in fully irrigated areas on permanent high beds of varying sizes. In contrast to the manual production in mainland China, beds are mechanically prepared and furrows are not usually used for plant production. Crops are almost exclusively fertilized with mineral fertilizers.

In Indonesia, the “sorjan” farming system refers to an integrated system of dryland and wetland farming simultaneously carried out on the same plot (SUDARYONO, 1988). The field is divided into alternate sections, either built up by bedding or lowered by digging out the soil (SJAHRI, 1975). The sorjan system as a traditional technique of Central Java is normally practiced in highly populated lowland and downstream areas which undergo periodic flooding and drought (DOMINGO & HAGERMAN, 1982). In rainfed areas, improved drainage on the raised beds and water impoundment in the depressions allows growing upland crops on the raised beds during the rainy

season and in the furrows during the dry season. In the rainy season, the furrows permit to extend the growing-season of lowland rice and provide a source of water for irrigating the raised beds (HUTABARAT & PASANDARAN, 1987). Therefore, the sorjan system has not only been implemented in low-lying areas of heavy clay soils and poor drainage in Java, but also introduced to tidal swamps, shallow peats, and areas with saline soils (MCINTOSH, 1985). In the latter, better aeration of the soil in the high beds promotes oxidation and leaching of acid sulfates. Dimensions of high bed (3 to 4-m wide, 0.4 to 1.5-m high) and furrow (3 to 10-m wide) were found to depend on availability of water and topography (BASA & ISMAIL, 1983).

A similar type of "ditch-and-dike" system as in Southern mainland China and Taiwan can be found in Vietnam and Thailand. In the Mekong-delta of Vietnam, permanent high beds are used on saline soil to overcome flooding and remove acid sulfates. Primarily cultivated are food crops such as cassava (RAUNET, 1994). In Thailand, high beds surrounded by permanently flooded furrows are employed 104 kilometers southwest of Bangkok near Nakhon Pathom and in the urban periphery of the capital. Maize and cassava are primarily cultivated distant from the city. Vegetables are the most important crops close to the city. The similarity to the Chinese cultivation systems can be attributed to the fact that many Thai vegetable growers are descendants of Chinese immigrants (KIEFT, 1994). The high beds are usually 4 to 6-m wide and up to several hundred meters long. In addition to permanently installed pumps to flood and remove water from the canal system, small pumps on hand-dragged boats are used to irrigate the beds. Canals and adjacent waterways fulfill the need for transportation of equipment and produce.

As a consequence of non-availability of vegetables and fruits, the nutritional situation is particularly serious in South Bangladesh. Reliance on the conventional land-use system of two rice crops and sometimes a subsequent dryland crop has created poverty, malnutrition, and seasonal unemployment (HAQ & DHAM, 1991) in tidally flooded, marshy areas. To stem this, a sorjan-type high bed cultivation system has recently been introduced and was found agronomically and economically suitable (ISLAM & DHAM, 1993). On the Andaman and Nicobar Islands ("Bay Islands"),

mainly tree crops are grown on soil beds elevated up to the highest tidal level and fish and prawns are raised in the channels between (SINGH & GANGWAR, 1989).

1.4 Approaches to Identify Soil-Water-Related Effects of Crop Management Technologies on Vegetable Growth

Besides an impact on soil nutrients, soil water affects vegetable growth by inducing water stress in plants, and modifying their root systems. Therefore, suitable measures of soil moisture stress and root development may be useful to gauge the effects of crop management technologies on vegetable performance.

If soil moisture is to be related to plant response, measurements of soil moisture tension are preferred over soil moisture content since they are a better measure of the availability of soil water to plants (GARDNER, 1960). In this thermodynamic terminology, movement of water in soil, its uptake by plants, and its loss to the atmosphere through transpiration is explained as a change in state from higher to lower free energy (BRADY, 1990). This energy is expressed as the soil matric potential. It can be measured as soil moisture tension which is the negative of the soil matric potential. Therefore, water moves from lower tension to higher tension (CASSELL & KLUTE, 1986). Integration of the variability in the soil-plant system over time during the growing period of a crop provides a way to evaluate the effect of soil physical conditions on crop growth (CALLEBAUT *et al.* 1982). WADLEIGH (1946) argued that since soil water tension cannot be maintained constant in the range of available water content, water stress in plants must depend upon the rate of change in soil moisture stress over the growth period. He defined a moisture stress value as an integral of measurements of soil moisture tension for time of crop cultivation period. TAYLOR (1952*a* and *b*) calculated "mean integrated soil moisture tension" as a double integral for time (crop cultivation period) and soil depth (depths where soil moisture tension was measured) and found significant relationships between values of soil moisture stress and crop yields. He exposed his crops to different degrees of drought stress and set the reference point of zero stress for zero tension. Consequently, better yields were associated with lower moisture tension. Including a correction factor for unequally spread time intervals between readings, the "mean integrated soil moisture tension" is:

$$T_{pm} = \frac{\sum_{i=0}^{m} \sum_{j=0}^{l} (d_{i+1} - d_i)\, T_{ij}}{l \sum_{i=0}^{m} (d_{i+1} - d_i)} \quad \text{[kPa]} \qquad (1)$$

where: T_{pm} is the total moisture tension, i represents a single time, j represents a single depth, l is the total number of depths, m represents the total number of readings, d represents the Julian day of the year when a reading was made, (d_{i+1}-d_i) is the time interval in days between successive readings, and T_{ij} is the moisture tension at a single time and a single depth.

The above-mentioned estimate of soil water stress takes only into account depletion of available soil moisture, but does not account for stresses caused by excessive soil water conditions. It follows that, in an environment where soil flooded conditions frequently occur, a soil moisture stress index should also include stress caused by excessive soil moisture. For this, the reference point of zero soil moisture stress should be set for more than zero tension, and the integration of soil moisture tension should include the absolute value of the deviates from the optimum. Stress can then be calculated as the sum of the absolute value of the deviates from the optimum soil moisture tension. “Mean integrated soil moisture tension” for time and soil depth then gives:

$$T_{pm} = \frac{\sum_{i=0}^{m} \sum_{j=0}^{l} (d_{i+1} - d_i)\, ABS(T_{ij} - T_{opt})}{l \sum_{i=0}^{m} (d_{i+1} - d_i)} \quad \text{[kPa]} \qquad (2)$$

where: T_{opt} is the “optimum” soil moisture tension.

The distribution of roots in the soil profile mainly determines the water uptake patterns of plants (GARDNER, 1964). Density distribution of root lengths coincides with root activity (RICHTER, 1987). Root density distribution reflects environmental conditions integrated over the time before measurement (BATHKE *et al.* 1992). Therefore, a measurement of root density distribution towards the end of the growing period

should reflect previous soil water conditions and should, in turn, be related to crop yield.

1.5 Objectives

The objective of this study was to evaluate the indigenous method of permanent high beds for their potential for increasing vegetable production particularly during the rainy season. Specific strategies were centered around management of soil water and included the following:

- To determine the influence of traditional flat beds and permanent high beds of varying widths on year-round vegetable growth with concern for water stress, root distribution, and yield
- To study the hydraulic properties of soils in permanent high beds

2 Materials and Methods

2.1 Measurements for Soil Moisture Tension

Soil moisture tension was measured in four vegetable crops (vegetable soybean, Chinese cabbage, chili, and carrot) from March 1994 until May 1995. Vacuum gauge tensiometers were installed in crop rows in one flat bed (one row), in one 2.0-m-wide high bed (two rows), and in two 3.0-m-wide high beds (three rows each) with two replications. Installation depth was 15 and 45 cm. Readings were taken at approximately two-day intervals from transplanting or seedling emergence until harvest of each crop. During the cultivation of each crop there were, however, periods when no readings could be taken, due to inaccessible wet field conditions.

2.2 Calculation of Water Stress

In this study mean integrated soil moisture tension was calculated for a single soil depth (15 cm), and for two depths (15 and 45 cm) according to Equation 2 on page 25. Optimum soil moisture tension was defined for each crop as the value for

which the regression of crop yield on mean integrated soil moisture tension fitted best.

2.3 Measurement of Root Length Density

Soil was sampled with a 2.0-cm-diameter punch tube to a depth of 60 cm in distances of 20 cm from the edge towards the center of the beds with two replications. The soil column was cut into 10-cm-long sections and roots separated by carefully washing the soil through a fine (0.15 mm) sieve. The roots were spread out uniformly in a petri dish and put upon a grid of lines with an interline distance of 1.27 cm. Root length in centimeter was determined using the "gridline intersect method" (NEWMAN, 1966) by counting the number of root/gridline intersects (GIOVANETTI & MOSSE, 1980). Three readings were made for each sample by rearranging the roots in the petri dish. Root length density (cm/cm^3) was calculated by dividing the mean of root length readings (cm) by the volume of the soil sample (cm^3). Since too many roots of weedy species were found in the topmost 10-cm soil depth, those data were excluded.

3 Results

3.1 Soil Moisture Tension and Water Stress

Water stress as a function of soil moisture tension depended on the distance of the average of soil moisture tension from the "optimum tension" and on the deviations from the optimum. Vegetable soybean in the dry season spring 1994 was mainly affected by stresses resulting from overdry soil conditions which were more pronounced on high beds. Soil moisture tension measured at 40-cm distance from the edge in the flat bed was less and amplitude smaller compared to all positions in the high bed (Fig. A-1). Therefore, curves of mean integrated soil moisture tension differed greatly between flat and high beds. High beds were more drought prone and water stress at the end of the cultivation period was consequently much greater than on flat beds.

Although cultivated during the rainy season, the Chinese cabbage crop in 1994 was not only affected by excessive soil moisture (at the beginning and at the end of the cultivation period), but also affected by deficient soil water between end of June and beginning of July (Fig. A-2). In the high bed, the edge (crop rows with 40-cm and 80-cm distance from the edge) was more exposed to overdry soil conditions as expressed by greater absolute tension and mean integrated soil moisture tension. Since soil water could be better controlled by pipe irrigation in the center of the high bed (crop row with 120-cm distance from the edge) and in flat beds, water stress was less in those positions.

Soil flooded conditions set in soon after transplanting chili in late July 1994. Soil moisture approached low tensions until the middle of September particularly on flat beds and in the center of the high beds (Fig. A-3). Development of soil flooding was reflected in the stress curves. In this phase, water stress were greatest for the flat bed and for the crop row with 120-cm distance from the edge of the high bed. After the begin of the dry season in autumn 1994 the course of soil moisture changed to a periodic pattern of drying and re-wetting typical for fully irrigated field conditions. Soil moisture tension in flat beds averaged lower values with smaller amplitude than on high beds in which higher averages and greater deviations were recorded towards their centers. Consequently, moisture stress increased more rapidly in the center of high beds.

Overdry soil conditions prevailed during the carrot crop in early 1995, similar to the vegetable soybean crop in spring 1994, although less pronounced. Soil moisture tension was greater on flat than on high beds throughout the cultivation period (Fig. A-4). Consequently, mean integrated soil moisture tension was greater in flat beds compared to high beds.

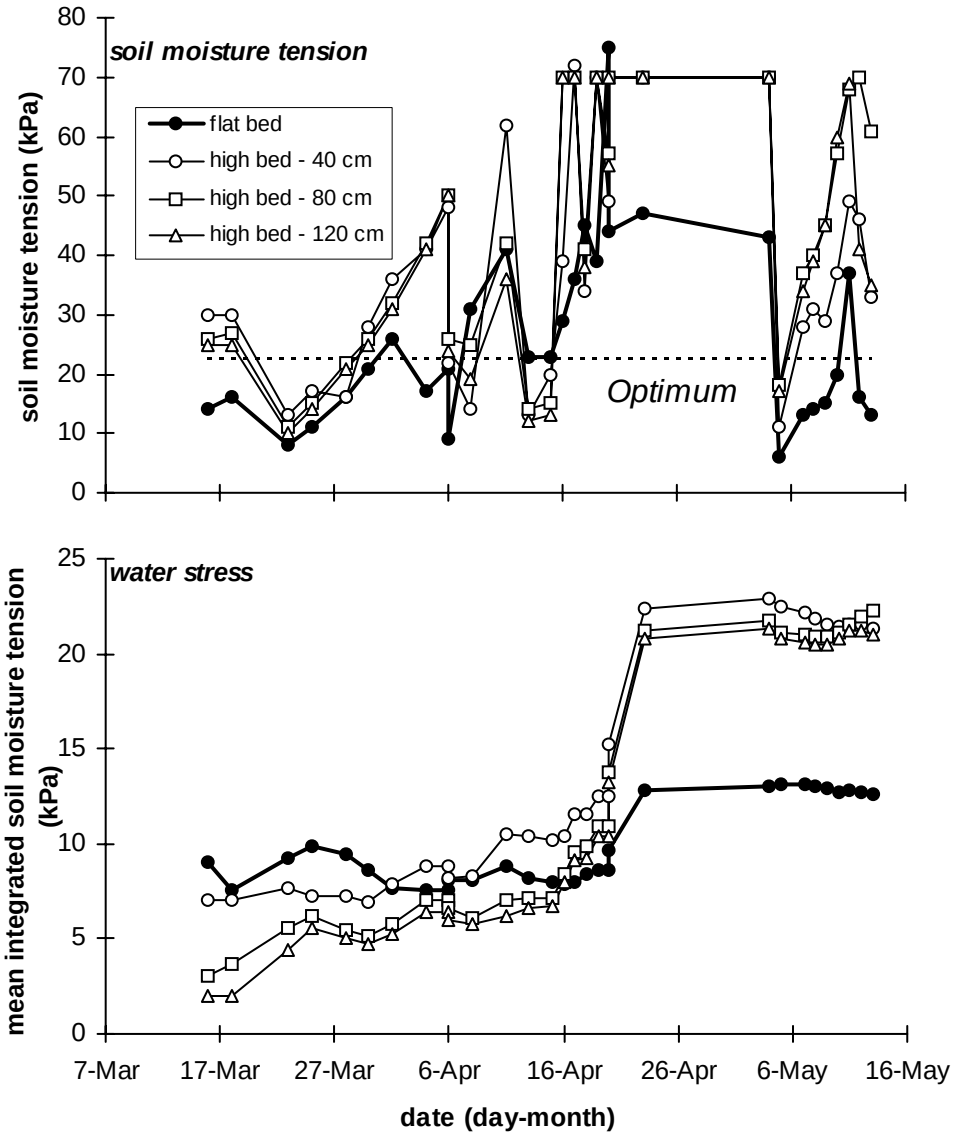

Fig. A-1 ***Soil moisture tension and water stress at 15-cm soil depth for vegetable soybean in flat beds (40-cm distance from the edge) and three positions (40-cm, 80-cm, and 120-cm distance from the edge) in high beds in 1994. The dotted horizontal line indicates the "optimum soil moisture tension"***

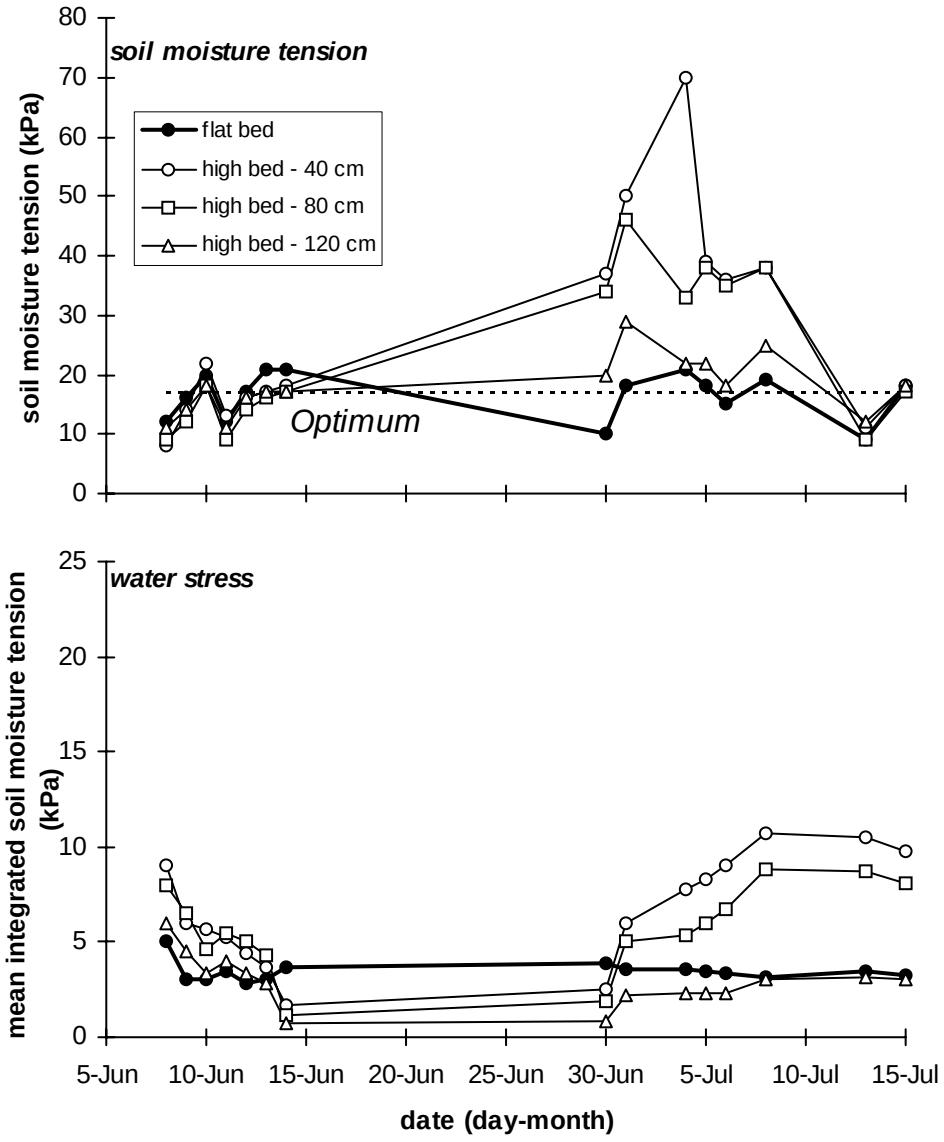

Fig. A-2 ***Soil moisture tension and water stress at 15-cm soil depth for Chinese cabbage in flat beds (40-cm distance from the edge) and three positions (40-cm, 80-cm, and 120-cm distance from the edge) in high beds in 1994. The dotted horizontal line indicates the "optimum soil moisture tension"***

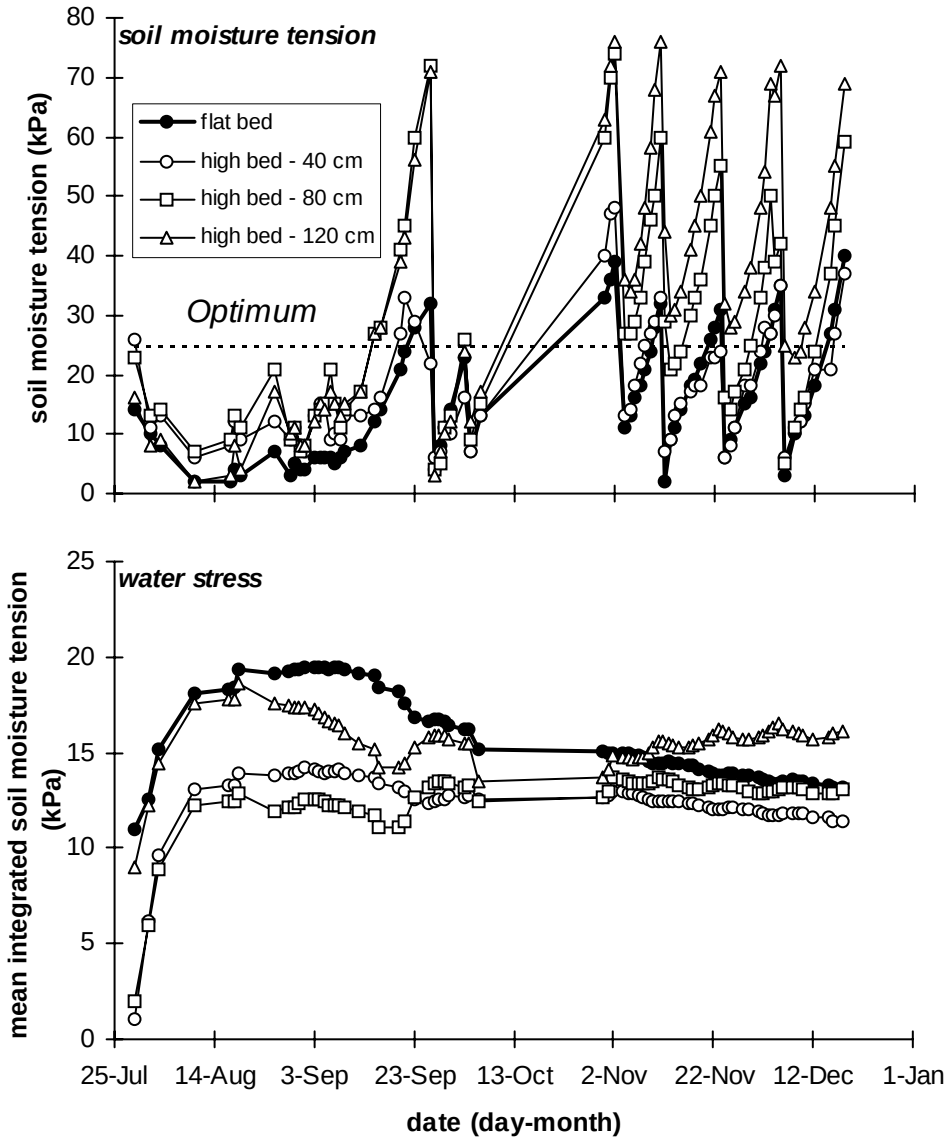

Fig. A-3 ***Soil moisture tension and water stress at 15-cm soil depth for chili in flat beds (40-cm distance from the edge) and three positions (40-cm, 80-cm, and 120-cm distance from the edge) in high beds in 1994. The dotted horizontal line indicates the "optimum soil moisture tension"***

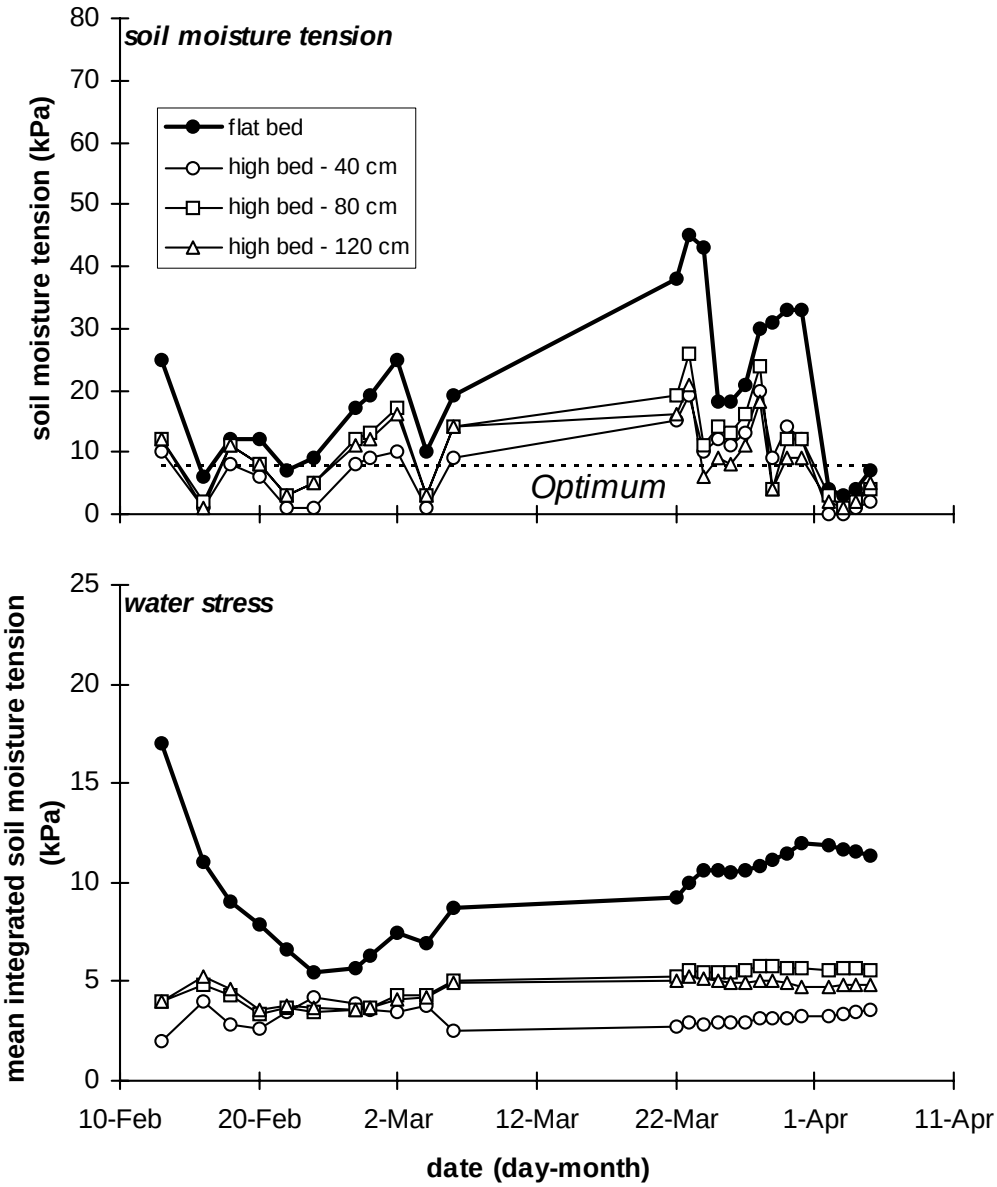

Fig. A-4 ***Soil moisture tension and water stress at 15-cm soil depth for carrot in flat beds (40-cm distance from the edge) and three positions (40-cm, 80-cm, and 120-cm distance from the edge) in high beds in 1995. The dotted horizontal line indicates the "optimum soil moisture tension"***

3.2 Effect of Water Stress on Vegetable Yields

For calculation of regressions of vegetable yield on water stress indices, data from flat and high beds were pooled. Yields of vegetable soybean and carrot during the dry season were more linearly related to the mean integrated soil moisture tension, whereas the relationship between yield and soil moisture stress was exponential for Chinese cabbage and chili during the rainy season (Fig. A-5).

The regressions were significant when soil moisture stress was calculated from soil moisture tension at 15-cm depth (Table A-1).

Table A-1 ***Optimum soil moisture tension (T_{opt}) for calculating mean integrated soil moisture tension and exponential regression ($y = a \cdot e^{(b \cdot x)}$; n = 9) of net yields (kg/m^2) on mean integrated soil moisture tension (kPa) over one soil depth (15 cm) and two soil depths (15 and 45 cm)***

Mean integrated soil moisture tension	T_{opt} (kPa)	Regression analysis [a]		
		a	*b*	r^2
Vegetable soybean				
15-cm depth	23	1.73 n.s.	- 0.026 *	0.42 *
15 and 45-cm depth	11	1.56 n.s.	- 0.016 *	0.39 *
Chinese cabbage				
15-cm depth	17	7.89 n.s.	- 0.746 *	0.74 *
15 and 45-cm depth	16	13.28 *	- 0.772 n.s.	0.65 n.s.
Chili				
15-cm depth	25	17.05 n.s.	- 0.308 *	0.63 *
15 and 45-cm depth	18	1.65 n.s.	- 0.177 n.s.	0.42 n.s.
Carrot				
15-cm depth	8	3.42 n.s.	- 0.024 n.s.	0.19 n.s.
15 and 45-cm depth	8	3.28 n.s.	- 0.023 n.s.	0.09 n.s.

[a] n.s.: not significant; * : significant at $P = 0.05$

Slopes (*b*) and levels of determination (r^2) were significant for vegetable soybean, Chinese cabbage, and chili. The equations were not suitable to estimate maximum yields of crops when no moisture stress occurred since the intercept (*a*) was not significant. The regressions were not improved by inclusion of mean integrated soil moisture tension at 45-cm soil depth. For Chinese cabbage and chili the levels of determination were less and the regressions were not significant. For carrot there was no clear relationship between yield and mean integrated soil moisture tension.

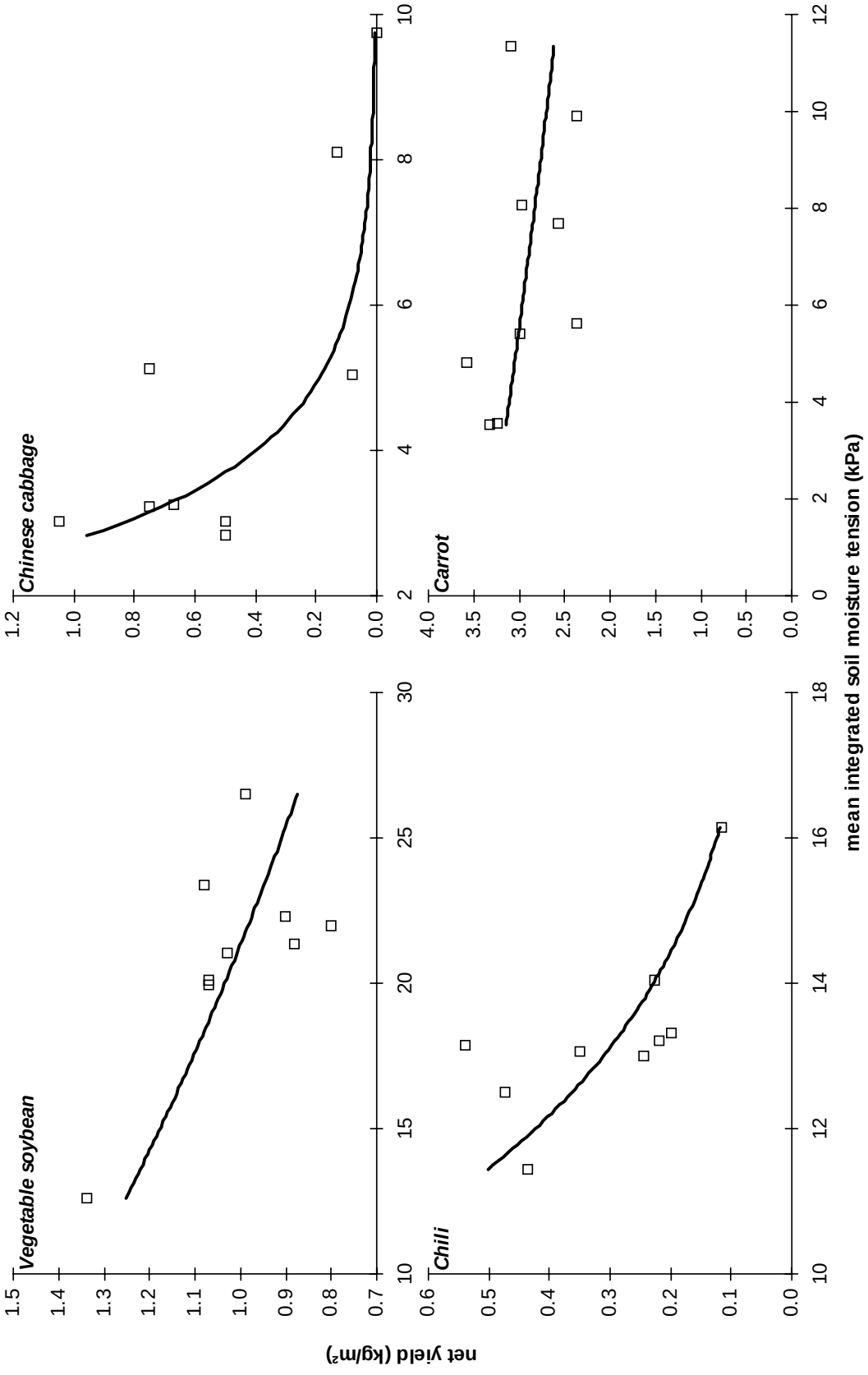

Fig. A-5 ***Vegetable yields as affected by water stress at 15-cm soil depth for four vegetables in 1994/95. Lines indicate exponential trends***

3.3 Gradients of Soil Moisture Tension in High Beds

Fig. A-6 shows vertical and horizontal gradients of soil moisture as influenced by soil moisture tension. A positive vertical gradient indicated water flow from 45 to 15-cm soil depth and a negative vertical gradient water flow in the opposite direction. When the horizontal gradient between the edge and the center of the high bed was negative, this indicated water flow from the edge towards the center, a positive horizontal gradient indicated water flow from the center towards the edge of the high bed. This horizontal gradient depended on both soil moisture tension and vertical gradient.

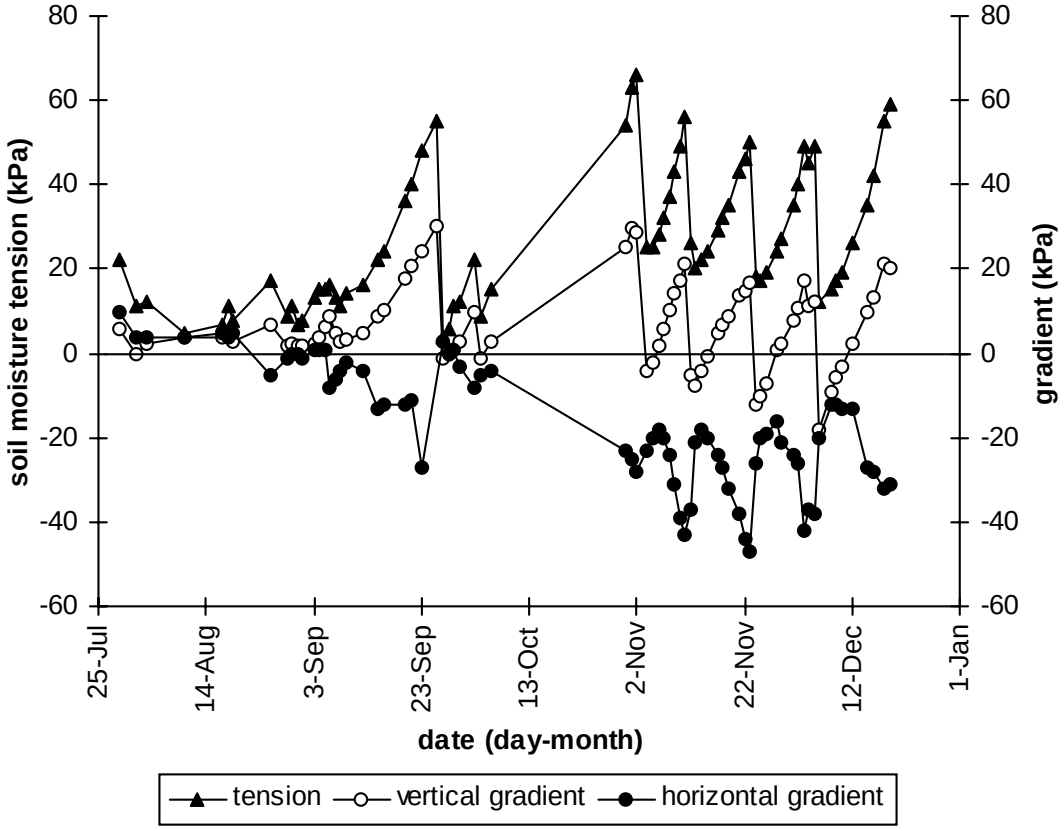

Fig. A-6 ***Soil moisture tension at 15-cm soil depth, vertical gradient of moisture tension between 15 and 45-cm soil depth, and horizontal gradient of moisture tension between 40 and 120-cm distance from the edge for chili on a 3.0-m wide high bed in 1994. Positive gradients indicate upward water flow for the vertical gradient and water flow towards the edge of the bed for the horizontal gradient***

The vertical gradient in soil moisture tension between 15 and 45-cm soil depth increased when the soil at 15-cm depth dried out (Fig. A-6): at the beginning of November the soil moisture tension at 15-cm depth increased to 70 kPa and the gradient between 15 and 45-cm depth increased to 30 kPa. Water flow was directed upwards. When the soil was re-wetted during the irrigation cycles in November and December 1994 and soil moisture tension consequently decreased, the vertical gradient became negative, indicating that the topmost soil layer was wetter than the deeper layer and water flow was directed downwards. The soil was saturated throughout the profile from end of July until early September. This was reflected in low soil moisture tension and a small vertical gradient. This small gradient indicated that excessive soil water could not be removed by vertical drainage. Under these conditions water moved from the inside towards the outside of the high bed, indicated by a positive horizontal gradient. Water that could not drain downwards when the soil was saturated and the water table close to the surface of the soil was removed horizontally into the furrows between high beds. When soil moisture tension increased the vertical gradient increased, and horizontal water flow was increasingly directed from the furrows towards inside of the high bed.

3.4 Distribution of Root Length Density

Root-length density was typically restricted to the top 50-cm soil depth (Fig. A-7) in flat and in high beds. Differences between vegetable species were not conspicuous although root systems of vegetable soybean and carrot were particularly shallow in flat beds. In those beds less roots elongated below 20 to 30-cm depth and were dark, thick, crooked, and without branches and root hairs. Root density in the whole profile was greater in high beds for all vegetables (Table A-2). Although roots did not stretch out much deeper into the soil and fewer roots were found above 20 to 30-cm depth, roots elongated more profusely in the 30 to 40-cm soil layer. Those roots were white, thin, well branched, and covered with many root hairs. Although anticipated, differences in root distribution across the width of high beds were not clear.

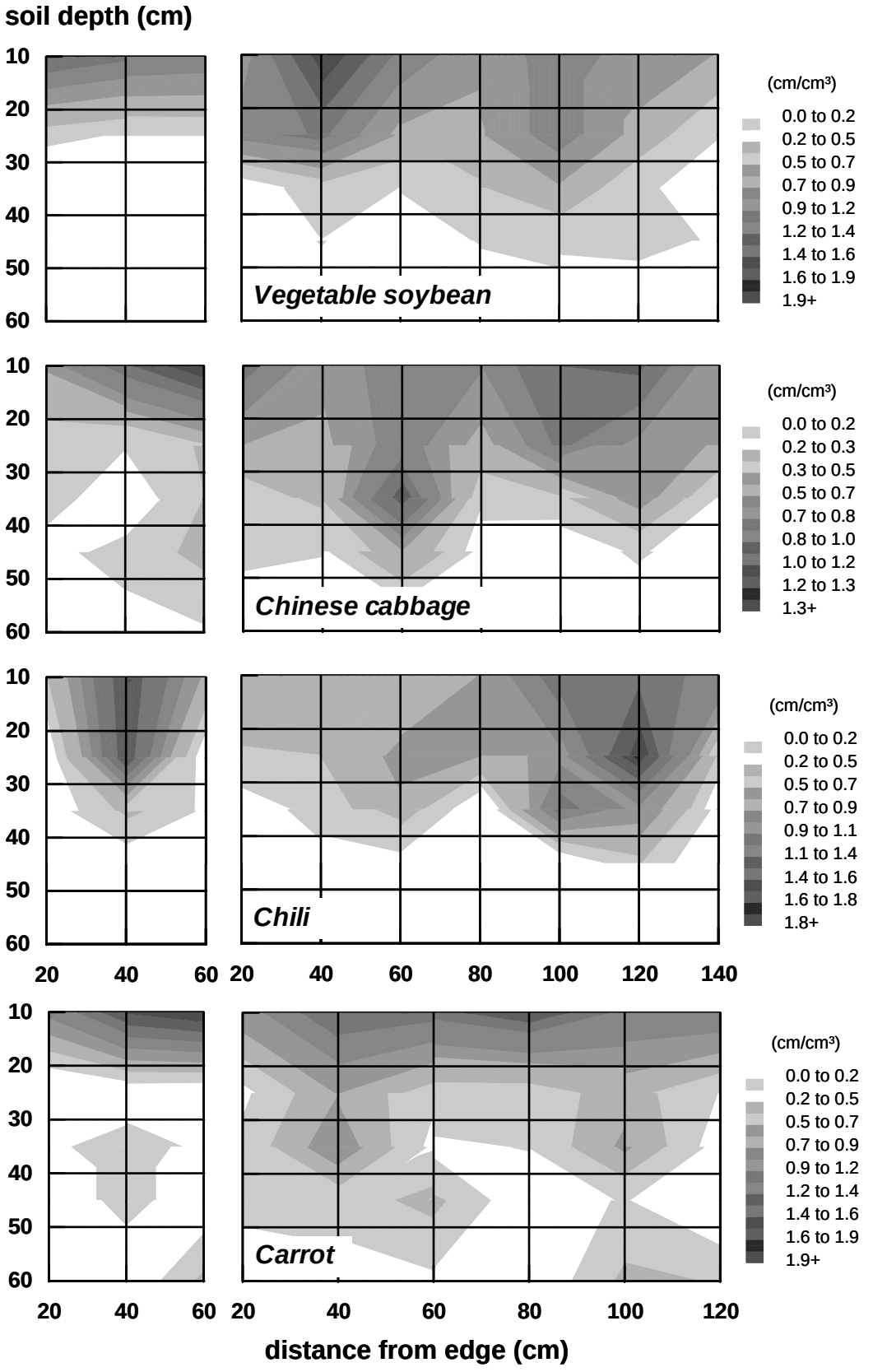

Fig. A-7 ***Distribution of root length density for four vegetables in (left) flat beds and (right) high beds in 1994/95***

Table A-2 ***Distribution of root length density (mean ± standard error; flat bed: n = 6, high bed: n = 14) of four vegetables on flat beds and high beds in 1994/95***

	Vegetable soybean		Chinese cabbage		Chili		Carrot	
Depth	Flat bed	High bed	Flat bed	High bed	Flat bed	High bed	Flat bed	High bed
(cm)	(cm/cm^3)		(cm/cm^3)		(cm/cm^3)		(cm/cm^3)	
10-20	1.27 ± 0.066	1.05 ± 0.151	1.00 ± 0.205	0.81 ± 0.083	0.93 ± 0.352	0.91 ± 0.150	1.52 ± 0.259	1.27 ± 0.096
20-30	0.30 ± 0.027	0.83 ± 0.133	0.29 ± 0.055	0.61 ± 0.065	0.59 ± 0.250	0.79 ± 0.180	0.26 ± 0.057	0.42 ± 0.081
30-40	0.03 ± 0.017	0.34 ± 0.079	0.22 ± 0.089	0.46 ± 0.128	0.29 ± 0.122	0.50 ± 0.171	0.25 ± 0.168	0.44 ± 0.130
40-50	0.03 ± 0.012	0.21 ± 0.048	0.26 ± 0.078	0.20 ± 0.062	0.06 ± 0.019	0.14 ± 0.064	0.16 ± 0.015	0.27 ± 0.085
50-60	0.01 ± 0.006	0.02 ± 0.019	0.03 ± 0.039	0.01 ± 0.018	0.01 ± 0.004	0.02 ± 0.012	0.01 ± 0.008	0.02 ± 0.009
Mean	**0.33**	**0.49**	**0.36**	**0.42**	**0.38**	**0.47**	**0.44**	**0.48**

3.5 Effect of Width of High Beds on Vegetable Yield

Vegetable yields were not significantly affected by width of high beds (Table A-3). Except for vegetable soybean in 1995, the influence of width was statistically not significant. This crop yielded better on the narrow, 2.0-m wide high bed. However, yield of vegetables within high beds varied considerably (Fig. A-8). This depended on the distance of individual crop rows from the edge of beds. During the dry season when carrot and vegetable soybean were grown, yields increased towards the center of high beds. This can be attributed to the irrigation system since irrigation pipes were located in the center of high beds and provided more water to the adjacent crop rows (Fig. A-8). Chinese cabbage was cultivated at the beginning of the rainy season. During this time of the year the weather is dominated by short, heavy rainfalls followed by longer periods without precipitation. During those dry periods irrigation water which was emitted from the central pipes was better available to the innermost rows of Chinese cabbage. During the peak rainy season when chili was grown, soils were completely inundated for prolonged times. Under these conditions, vegetable yields were better on the outside of high beds and decreased towards their centers.

4 Discussion

4.1 Effect of Permanent High Bed Technology on Soil Water

The weather at the experimental site is characteristic of climatic conditions in many tropical and subtropical environments. The dry seasons were virtually without any rainfall. In the transition from/to the rainy seasons some scattered rainfalls occurred, but the difference between evaporation and precipitation reached its' yearly maximum since sunshine intensity was high. Rainfalls were heavy and extensive in the rainy season, peaking in July and August when the water table approached the soil surface. Nevertheless, even this season is not without periods of clear and dry weather in which vegetables need irrigation. This stresses the need for a close monitoring of soil water throughout the year in tropical vegetable production.

Table A-3 ***Marketable yield of vegetables on high beds as influenced by bedwidth from 1992 to 1995***

Year	1992		
Vegetable	Chinese cabbage	Common cabbage	Tomato
Analysis of variance (kg/m^2)			
2.00 m	1.67 a [a]	2.23 a	4.28 a
2.75 m	1.50 a	2.16 a	4.59 a
3.50 m	1.23 a	2.10 a	4.77 a
Significance level (*P*-value)	*0.09*	*0.46*	*0.50*

Year	1993			1994			1995		
Vegetable	Chinese cabbage	Chili	Carrot	Vegetable soybean	Chinese cabbage	Chili	Carrot	Vegetable soybean	Chinese cabbage
Analysis of variance (kg/m^2)									
2.00 m	2.14 a	0.554 a	1.20 a	1.12 a	1.64 a	0.297 a	3.16 a	1.36 a	2.72 a
3.00 m	2.10 a	0.595 a	1.06 a	1.02 a	1.67 a	0.359 a	3.07 a	1.23 b	2.68 a
Significance level (*P*-value)	*0.77*	*0.70*	*0.61*	*0.38*	*0.93*	*0.19*	*0.24*	*0.02*	*0.79*

[a] Mean separation by LSD test at $P = 0.05$; means in each column followed by the same letter are not significantly different

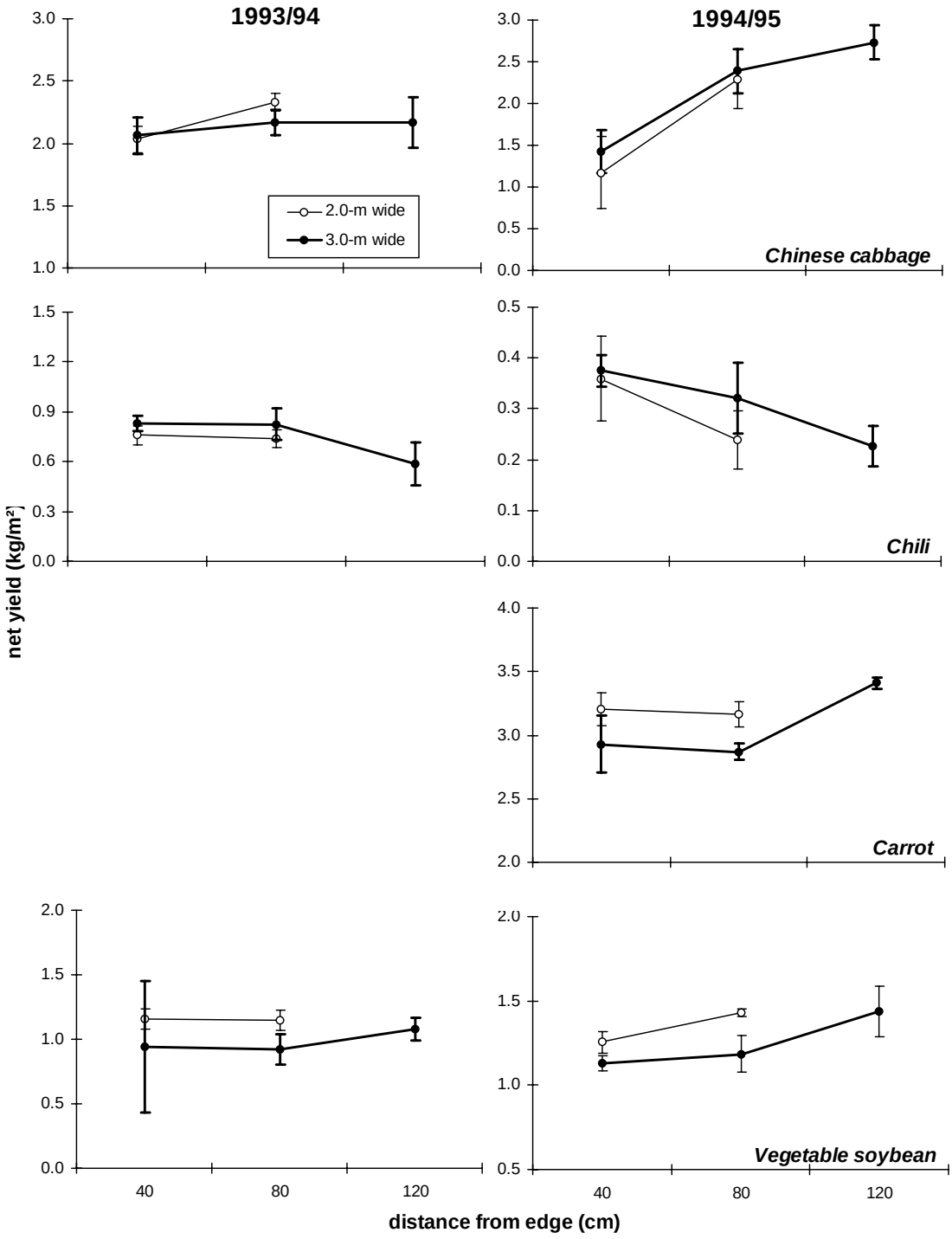

Fig. A-8 ***Marketable yield of four vegetables on 2.0-m wide and 3.0-m wide high beds as influenced by distance of crop rows from the edge of the bed 1993/94 and 1994/5 (no data for carrot in 1993/94). Error bars indicate standard errors (n = 40)***

High beds improve hydraulic conditions of soils under wet conditions. In tropical lowlands, water tables are frequently close to the surface during the rainy season. After some time without precipitation the topmost soil layer will dry out. Although the surface soil may then be distinctively drier than the water-logged soil beneath, water supply through rainfall will quickly exceed the soil's limited rate of absorption (water-holding capacity). This is particularly true for soils in tropical lowlands when they are managed for the cultivation of rice. When the water table is close to the soil surface and the soil above is saturated, vertical infiltration diminishes as the gradient in moisture-potential between the upper and the lower soil layer approaches zero tension (HILLEL, 1980). If surface runoff is limited, flat planting beds will become entirely water-logged then. Excessive soil water can neither drain downwards nor into the shallow furrows which are rapidly filled with water after heavy rainfall. The deep furrows between high beds have much more capacity to drain and store water. They act as a sink into which excessive soil water flows along a horizontal hydraulic gradient. This gradient is directed from the inside towards the outside of the high bed. Figure A-6 revealed that low soil moisture tension in the upper and lower soil layer and, consequently, a small vertical gradient are a prerequisite for horizontal drainage.

During the rainy season a sink, the flooded furrows acted as a source to supply high beds with water during the dry season. Crop demand and evaporation deplete soil water in the surface layer. When moisture tension in this layer and the gradient between topsoil and subsoil was high, water flow from the edge towards center was maximal. However, irrigation proved to remain crucial for crop production even though furrows were continuously flooded. The low height of standing water suitable for production of aquatic crop was not sufficient to provide all water necessary for vegetable production on high beds. In similar cultivation systems in Southeast Asia furrows are flooded to higher levels but they can still supply only a part of crop water needs.

Vegetable yields varied with soil water conditions in different positions in high beds. This has implications for adjustment of high-bed dimensions: height of beds primarily depends on their width since the latter determines the amount of soil material available when width of furrows is fixed. If space allocation to high bed

(vegetable) cultivation area is to be maximized for a given unit of land, then high beds should be as wide as practical for easy and quick management of vegetable cultivation practices. The "optimum" width of high beds depends on (1) regional rainfall conditions, and on (2) irrigation as they modify soil water conditions.

(1) During periods of continuous heavy rainfall as in July and August 1994 when chili was cultivated, the center of high beds was more rapidly inundated then the edge (Fig. A-3). Consequently, water stress was greater in the center. This is clear since the gradient of soil moisture tension was directed towards the edge of beds and excessive soil water could be removed more quickly from the edge of high beds. Under conditions of prolonged heavy monsoon rains as in South India, equatorial Malaysia and Indonesia, narrower beds are called for to avoid yield losses in the center of high beds which are more rapidly affected by inundation. However, under weather conditions as in Taiwan with a quick succession of heavy, short rainfalls and dry, sunny periods, wider beds are presumably more advantageous for year-round vegetable production.

(2) During dry periods water stress decreased towards the sources of irrigation. Those were the flooded furrows between beds and the pipe irrigation in the center of beds. The distance between standing water in the furrows and the absorbing root zone of vegetables increases with height of beds. When beds were newly built and, therefore, their height greater, pipe irrigation was more important than the water supply from the furrows. This is reflected in soil water conditions during the rainless period at the beginning of July 1994 when Chinese cabbage was cultivated (Fig. A-2): soil moisture tension and water stress was much greater on the edge of high beds and decreased towards the pipe irrigation in the center. This could also be attributed to the greater soil surface exposed to evaporation on the high edges. Under these conditions, vegetable performance depended primarily on the pipe irrigation system. When beds were eroded to a lower height after the heavy rainfalls in July and August 1994, water supply from the furrows gained advantage: After the beginning of November 1994, soil moisture tension and water stress in chili was greater in the center of beds and decreased towards the edge (Fig. A-3). Since beds were eroded, the distance between water in the furrows and the root zone of vegetables was smaller, and less water could evaporate from the lower edges. It follows that a greater width and height of beds can be advantageous when efficient irrigation facilities are available. However, irrigation systems cannot overcome excessive soil water during the rainy season. Therefore,

adjustment of dimensions of high beds should primarily follow regional weather conditions for year-round vegetable production.

4.2 Effect of Water Stress on Vegetable Production

The term "water stress" refers to the effects of deficient and excessive soil water on plant growth. These effects are primarily related to deficient soil water for plant uptake under dry soil conditions and to low concentrations of soil oxygen or high concentrations of carbon-dioxide and ethylene in the root zone of crops under wet soil conditions. During the growth of vegetable soybean in the dry season, water stress as indicated by "mean integrated soil moisture tension" was primarily related to stresses caused by overdry soil conditions (Fig. A-1). Chinese cabbage and chili grown during the rainy season and subsequent early dry season were affected by stresses caused by both excess and deficit soil water (Figs A-2 and A3). Under these conditions, the relationship between water stress and yield was clearly exponential. The high values of the slope *b* in the regression equations (Table A-1) indicate that extreme values of soil moisture tension exerted an exaggerated effect on crop growth. Since this was true only in the rainy season, overwet soil conditions indicated by low moisture tensions explained the greater part of variations in yield. The insignificant estimates of maximum crop yield when no water stress occurred (parameter *a*) were partly an extrapolation problem since no real soil moisture treatments were imposed and the number of observations was limited. The study accounted for crop-specific sensitivities to water stress (T_{opt}) but not for the fact that these sensitivities may also vary with stage of crop growth (HILER *et al.* 1972). The influence of water stress on carrot yield was insignificant presumably because soil moisture tension was near-optimum throughout the cultivation period so that soil moisture was not a growth-limiting factor.

Optimum soil moisture tensions calculated for individual crops showed increasing tolerance to over-wet soil conditions in the order: chili, vegetable soybean, Chinese cabbage, and carrot. The sensitivity of chili to soil inundation is well known. The ability of grain soybeans to acclimatize to saturated soils in seasonally waterlogged tropical lowland areas was assumed to have developed during the long period of domestication in rice-based Asian agriculture (LAWN, 1985). However, prolonged flooding may significantly reduce soybean growth (SALLAM & SCOTT, 1987). This

was found to be due to its sensitivity to low oxygen concentrations even when soil matric potential was maintained close to optimum (SOJKA, 1985). Soybean varieties for vegetable consumption are particularly sensitive to unbalanced water supply (TSOU, personal communication). Chinese cabbage is largely intolerant to soil flooding. However, T_{opt} for Chinese cabbage was lower than for chili and vegetable soybean in this study, pointing out the importance of well balanced, yet sufficient soil moisture. For carrots, high and particularly steady water supply was described as a prerequisite for high yields (KRUG, 1991).

4.3 Effect of Permanent High Beds on Root Distribution of Vegetables

Although differences in root-growth characteristics were anticipated, they varied not much among the vegetable species (Fig. A-7). Even though plant species have individual root growth characteristics, these can be substantially modified by environmental conditions: cultivated plants subjected to drought often develop deep, profusely branched root systems to absorb water and nutrients from a large volume of soil. However, when grown with irrigation and fertilization, smaller root systems may be sufficient (KRAMER, 1983). Greater root growth under those conditions may only indicate partitioning of greater energy to the root system and not an increase in water and nutrient uptake (DEVITT, 1989). In hydroponics, saturated soil culture, areas with high water tables, or under high irrigation rates, roots accumulate close to the soil surface (PROTOPAPAS & BRAS, 1987).

Roots of vegetables typically accumulated above 40-cm soil depth and inclusion of soil moisture tension at 45-cm soil depth did not improve the estimation of yield as a function of water stress. GARDNER (1964) stated that once root distribution in the soil profile is known, measurement of soil moisture tension at a single appropriate depth was sufficient for controlling irrigation. In retrospect installation of tensiometers at a depth of 20 cm would be sufficient under soil conditions in tropical lowlands. Root density and distribution could be explained by the soil properties in this rice-based environment and its' modification through construction of high beds. However, soil water may have played a significant role: when soil moisture was temporarily deficient during cultivation of vegetable soybean, roots elongated more profoundly to deeper soil layers in high beds. Yields were, however, lower than on

flat beds, suggesting that too much photosynthate was diverted into root growth at the expense of shoot growth and yield (Table B-1). Other reports (e.g. HEATHERLY, 1980) show that more root mass was required to support soybean shoot growth when cultivated in dry soil. In more flood-prone flat beds, root systems of vegetables were typically restricted to the uppermost soil layer during the rainy season. Flooding may lead to the death of deeper roots and often the proliferation of adventitious and surface roots. This may expose them to more favorable chemical and physical conditions (JONES *et al.* 1991), but can make them more sensitive to subsequent drought (JACKSON & DREW, 1984). Yields of rainy-season chili on flat beds were much lower than on high beds, indicating that adventitious rooting may have helped chili to recover from flooding, but that these roots may have only incompletely replaced the functions of the original roots.

B Effects of Permanent High Beds on Vegetable Production — Soil Nitrogen

1 Introduction

1.1 Nitrogen Needs of Vegetables

Of the various essential elements, nitrogen is the one of greatest importance to plants (VIETS, 1965). Many crops, including vegetables, respond quickly to applications of nitrogen and need nitrogen in quantity for optimum development (BRADY, 1990). On the other hand, excess nitrogen can be harmful. The molecular state in which exchangeable nitrogen is absorbed is important. Several authors have discussed the potentially injurious effects of ammonium nutrition to vegetable species and its' alleviation through nitrate (e.g. BARKER & MILLS, 1980; IKEDA, 1991). Root development plays an important role in absorption of nitrogen in the soil.

Limited root development triggers tipburn in Chinese cabbage. Flooded soil conditions are one reason for restricted root growth (Chapter A). Soil nitrogen can be another: roots of Chinese cabbage are susceptible to ammonium and complete root systems can be damaged by excess soil ammonium (IMAI, 1987). Uptake and translocation of calcium in tissues can be competitively suppressed by NH_4 and other monovalent cations. High supply of ammonium from the soil can retard metabolism of NH_4-N to protein, followed by accumulation of potentially toxic concentrations of NH_4 in tissues (AVRDC,1986).

Excess plant-available nitrogen in the soil can induce internal rot (rotting of inner leaves) in Chinese cabbage. Oversupply of soil nitrogen stimulates vegetative growth. If growth is too rapid, this may result in too compact heads and the high "head pressures" can destroy tissues of inner leaves (IMAI, 1987).

The root system of chili is extremely sensitive to environmental stress. Excessive

nitrogen can induce damage in chili roots resulting from a high concentration of soluble salts in the soil. This is usually expressed by wilting of plants particularly in the seedling stage (AVRDC, 1992). However, at low contents of soil-N, fruit set in chili may be significantly reduced. Application of nitrate was suggested to overcome anaerobic stress in chili: the stimulation of nitrate reductase activity may enable chili to resist flooding by reduction of nitrate to nitrite (AVRDC, 1989).

1.2 Relevance for Vegetable Production in Tropical Lowlands

In tropical lowlands, vegetables are commonly rotated with rice. Cultivation of rice under flooded, i.e. anaerobic soil conditions can be unfavorable for the cultivation of vegetables. Rice can absorb ammonium-nitrogen more effectively than nitrate-nitrogen since roots of graminaceous plants show comparatively low values of cation-exchange capacity and are, therefore, more effective in absorbing monovalent cations (NÕMMIK, 1965). In contrast, most vegetable species are dichotyledonous plants and their roots absorb NO_3 considerably more rapidly and even against concentration gradients (SCARSBROOK, 1965).

Soil water exerts a strong effect on the availability of nitrogen (MILLER & JOHNSON, 1964). Mineralization of soil organic nitrogen was found to proceed most rapidly at low soil moisture tensions of 3 to 10 kPa in some soils (STANFORD & EPSTEIN, 1974). In flooded soils, the resulting ammonium nitrogen will accumulate because of the lack of oxygen for nitrification. However under drier upland conditions, NH_4 is usually quickly oxidized to NO_3 which can accumulate at substantial levels if leaching is minimal (TERRY & TATE, 1980). Under certain circumstances nitrification of ammonium may be adversely affected: excessive soil moisture and high temperatures may harm this biological process (JUSTICE & SMITH, 1962).

Availability of soil nitrogen to lowland or upland crops is affected by various processes: (1) denitrification of nitrate to N_2O and N_2, (2) immobilization of ammonium-N by microorganisms, (3) fixation of ammonium to clay minerals and its' release, (4) leaching of ammonium, and (5) leaching of the highly mobile NO_3-ion.

(1) 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 is oxidized to NO_3 in these sites. Nitrate is then leached into underlying anaerobic soil layers to be possibly denitrified to N_2 and N_2O, gases which are known to destroy the atmosphere's ozone-layer (PATRICK & WYATT, 1964).

(2) Fertilizer-NH_4 can be immobilized by microorganisms (SOWDEN, 1976). The microbial flora is restricted to the uppermost soil layer where more O_2 is available, so that immobilization proceeds close to the surface.

(3) Clay minerals such as illite or vermiculite can immobilize ammonium by entrapping NH_4-ions between their silicate sheets (DRURY & BEAUCHAMP, 1991). Although ammonium is much less mobile in soil then nitrate, most of this fixation occurs in subsoils where the content of N-fixing clays is usually higher. Fixed (non-exchangeable) 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, this fixed NH_4 can be released (ALLISON *et al.* 1953).

(4) Leaching of NH_4 from the topsoil can occur when exchangeable ammonium is not oxidized to nitrate in anaerobic soils and when this NH_4 is not immobilized by microbes. Leaching of ammonium from subsoils can occur when the concentration of NH_4 exceeds the capacity of the fixing sites in clays to sorb the ammonium (HARMSEN & KOLENBRANDER, 1965).

(5) N-losses by leaching of NO_3 are of great concern (KOCH, 1987). This environmental hazard can be particularly serious when a wetland rice environment is converted to upland vegetable production (Fig. B-1). Organic matter that accumulates much greater under anaerobic conditions decomposes rapidly. Physical disturbance (tillage, weeding) can cause a stimulation of mineralization. As a result, organic matter is depleted and losses of NO_3 can occur through leaching and denitrification after heavy rainfall, or when the field is shifted back to flooded rice production.

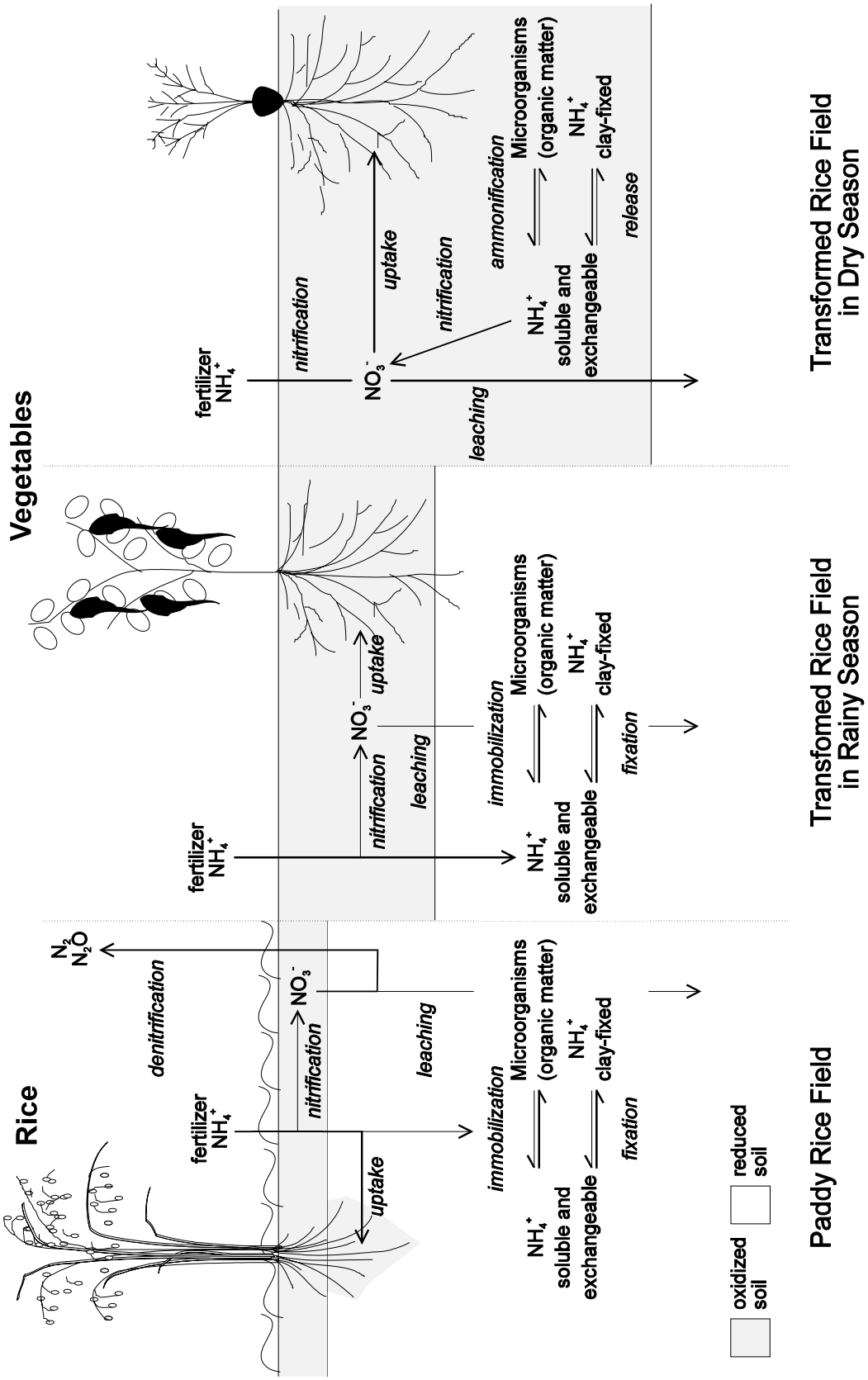

Fig. B-1 *Nitrogen transformation in soils of tropical lowlands*

1.3 Objectives

The objective of this study was to evaluate the effects of permanent high beds on soil nitrogen in year-round vegetable production in tropical lowlands. Specific objectives were:

- To evaluate the impact of seasonal variations in soil moisture on availability of soil nitrogen to vegetables
- To determine potentially harmful effects of soil nitrogen on vegetables
- To investigate transformations of nitrogen from fertilizer in soil
- To determine the relative importance of water stress and availability of soil nitrogen on vegetable production
- To estimate leaching losses of soil nitrogen in vegetable production

2 Materials and Methods

2.1 Soil Nitrogen Analysis

Soil was sampled 0 to 30-cm deep and 30 to 60-cm deep (three samples per plot) with a 2.0-cm-diameter punch tube at weekly intervals from November 1993 until May 1995. Samples were taken with four replications in flat beds and 3.0-m-wide high beds where the standard N rate was applied.

Between sampling and analyzing, samples were stored in a cooler. Soil was extracted for two minutes in 0.8 % KCl aqueous solution by 1:2 in volume while stirred by an electric mixer. Samples were filtered and analyzed for NO_3 and NH_4 using Merck's RQflex reflectometer with Reflectoquant nitrate (5 to 225 ppm), and Reflectoquant ammonium (0.2 to 7.0 ppm) analytical test strips. The same extract was used for both analyses. The advantage of this method is that several ions can be analyzed with ion-specific test-strips without calibration and further laboratory equipment. Disadvantages are the limited concentration ranges and costs of the strips. Each batch of test strips is supplied with a bar-code which contains information for wavelength correction and a batch-specific calibration curve. The bar-code initializes the

battery-powered, hand-held reflectometer. Each test strip has two reactive pads to produce a mean value. Before analysis, the meter's clock was started at the same time as the strip was dipped into a sample. Five seconds before the clock counted down a test-specific time (NO_3: 60 seconds, NH_4: 8 minutes), the strip was inserted into the meter and a concentration value displayed. The meter was tested against a range of nitrate standard solutions with satisfactory results. HOLDEN & SCHOLEFIELD (1995) confirmed the reliability of the test. All readings were calculated from concentration (ppm) to amount (kg/ha).

2.2 Study of Transformation of Fertilizer Nitrogen in Soil

To study the effect of application of N fertilizer on transformation in soil, ammonium sulfate was applied at a rate of 60 kg N/ha to flat and high bed plots with three replications. Plots were kept free of crops and weeds. The fertilizer was applied on three different dates: 11 January, 23 March, and 13 June 1995. Soil was analyzed for NH_4 and NO_3 in samples taken from the 0 to 30-cm soil layer (three samples per plot). Daily measurements were continued for up to three weeks until ammonium concentrations were less than 1 ppm. Content of soil nitrogen before fertilizer application was subtracted from measured concentrations after application.

2.3 Rating of Effects of Growth Factors on Vegetable Production

To estimate which of the two growth factors soil water and soil nitrogen limit year-round vegetable production more decisively, a regression of vegetable yields on water stress and soil nitrogen was performed. Data were derived from crops of vegetable soybean in the dry season 1994, Chinese cabbage and chili in the rainy season in 1994, and from carrot in the dry season in 1995. Indices for water stress were the mean integrated soil moisture tension at harvest of each crop (Chapter A). Indices for soil nitrogen were the averages of soil NO_3 content during the cultivation period of each crop. The calculation was based upon data from four plots (one plot in flat beds and three plots in high beds) where water stress was measured.

For each vegetable crop, an average for yield, water stress, and soil nitrate content was calculated from the data of individual plots. Data from individual plots were then transformed to percentages of their joint mean. The pooled data for all crops was analyzed with multiple regression of (relative) net yield on (relative) water stress and (relative) soil-NO_3 content (n = 12).

3 Results

3.1 Soil Nitrogen

Root density was little below 40-cm soil depth and water stress measured at 45-cm depth was not correlated with vegetable yields (Chapter A). This allows the assumption that only soil nitrogen at 0 to 30-cm depth was available to vegetables. Soil nitrogen at 30 to 60-cm depth was beyond the reach of roots and, therefore, subject to loss by leaching or denitrification. Contents of soil ammonium below 30-cm depth were never greater than a few kilograms per hectare. The seasonal variations in precipitation were reflected in contents of soil nitrate in flat beds and in high beds: soil nitrate was high during the dry season and low during the rainy season (Fig. B-2). Fertilizer applications significantly increased soil nitrate at 0 to 30-cm depth on flat beds during the rainy season. This was particularly pronounced when the basal application and the first side dressing was applied to chili in the peek rainy season 1994. However, nitrate contents decreased in a few weeks. On high beds, application of N fertilizer was not much reflected in soil nitrate in the root zone.

Soil nitrate peaked at the end of the dry season in April and May 1994 at both 0 to 30-cm depth and 30 to 60-cm soil depth. Nitrate content at 30 to 60-cm soil depth was greater in flat beds than in high beds.

3.2 Transformation of Nitrogen from Fertilizer in Soil

Biological oxidation of ammonium to nitrate follows Michaelis-Menten reaction kinetics (RICHTER, 1987). The nitrification process of NH_4 from ammonium sulfate in soil without crops during different seasons and in different cultivation systems is presented in Fig. B-3.

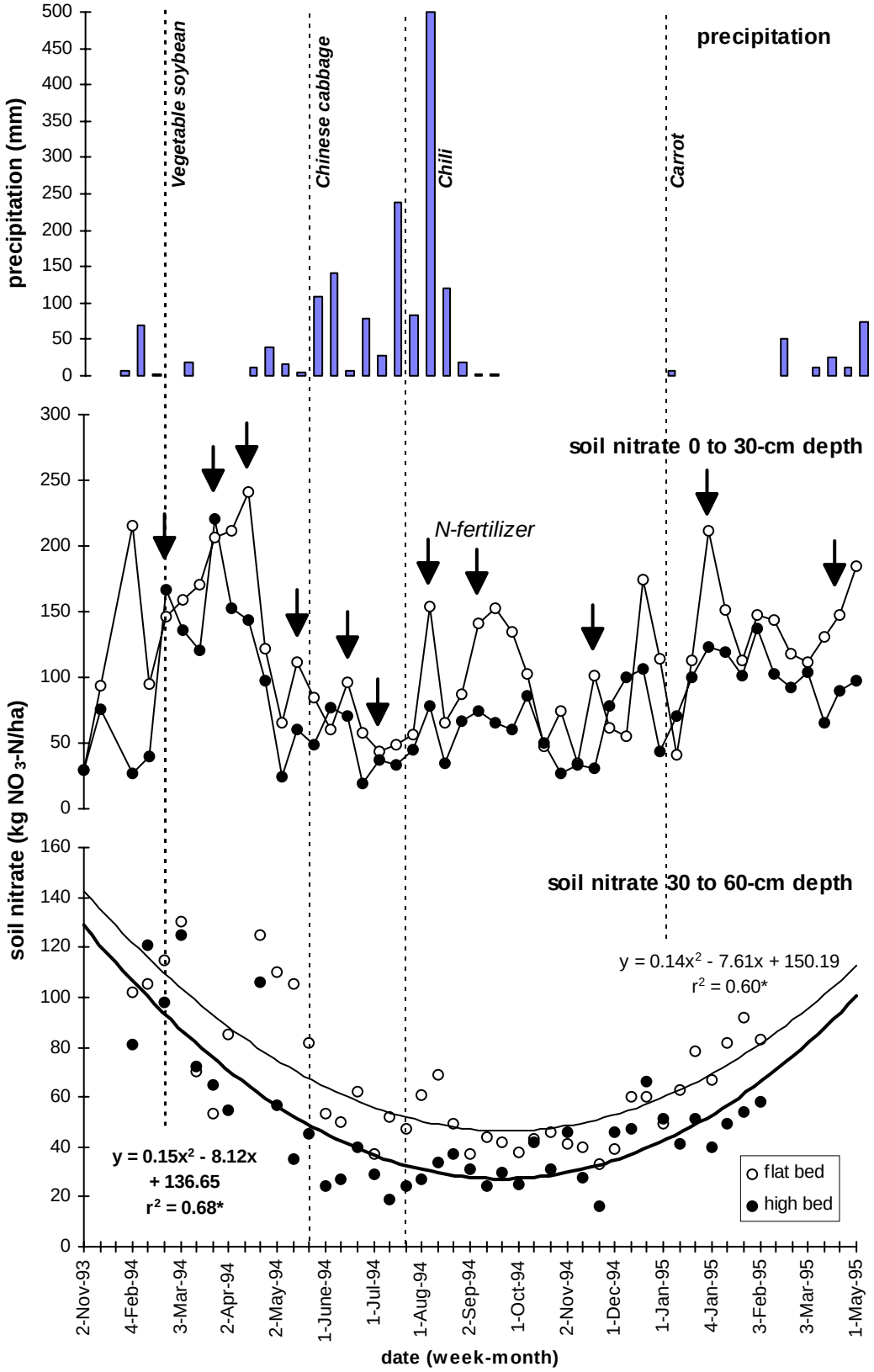

Fig. B-2 ***Weekly precipitation and soil nitrate at two soil depths in flat beds and high beds. Arrows indicate application of N-fertilizer, lines indicate quadratic trends for (thin line) flat and (thick line) high beds***

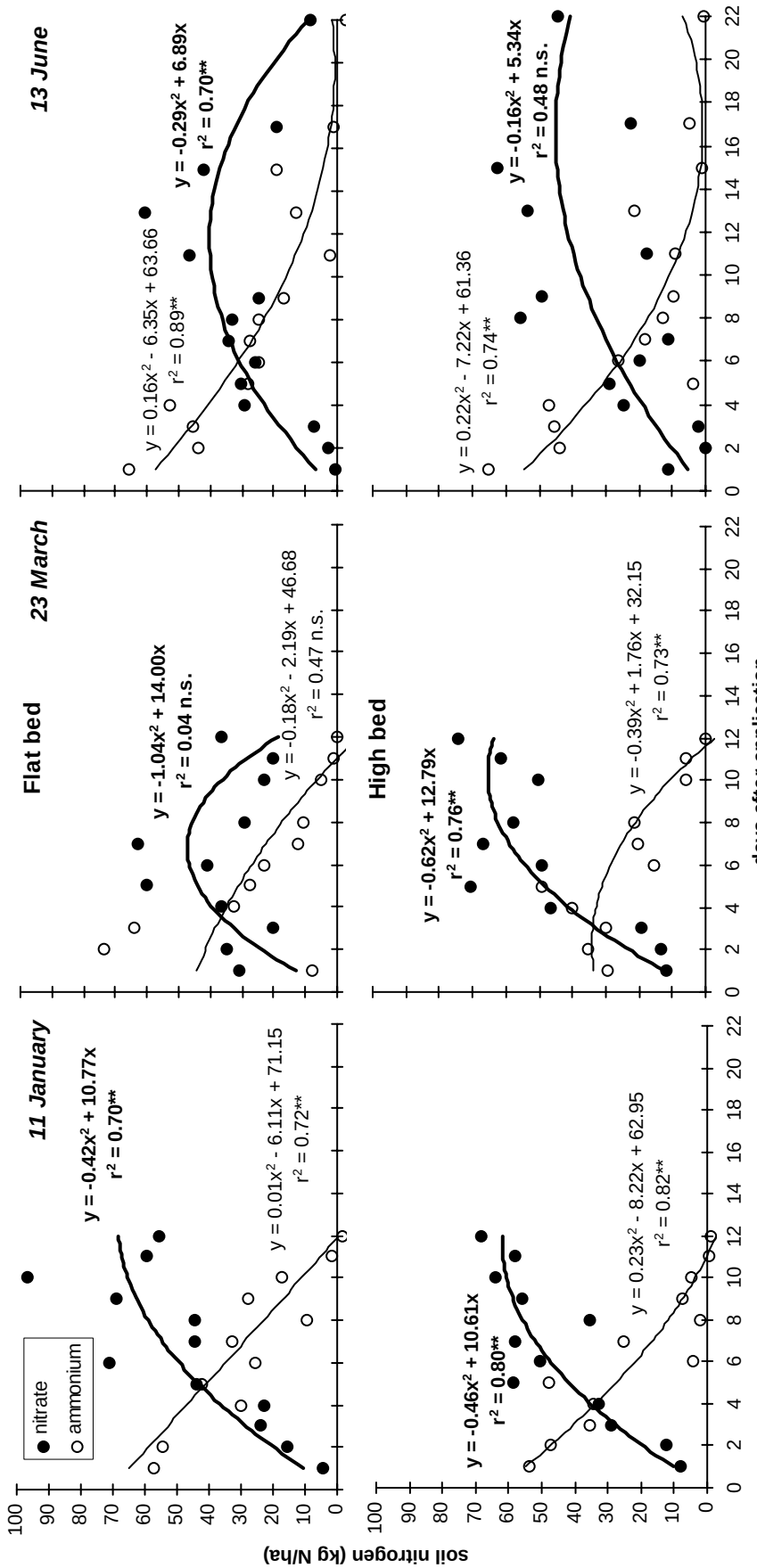

Fig. B-3 *Transformation of nitrogen from ammonium fertilizer in soil. 60 kg N/ha as ammonium sulfate were applied at three times in 1995 to flat beds and high beds. Lines indicate quadratic trends for (thin line) NH_4-N and (thick line) NO_3-N*

Hyperbolic-type decreases in ammonium and increases in soil nitrate were approximated with quadratic regressions. In the dry season in January 1995, ammonium was completely oxidized to nitrate in flat and high beds within 12 days after application. Although irrigation water was applied at rates of 17, 9, and 25 mm on days 1, 5, and 9, soil moisture tension did not fall below 10 kPa throughout this experiment. Irrigation rates in the second experiment during the transition phase from dry to wet season in March were 38 mm on day 1 and 22 mm on day 5. Up to day 8, soil moisture tension was above 10 kPa, but fell below that after rainfall of 49 mm and 7 mm on days 8 and 10. Nitrification proceeded in a similar way as in the first experiment, but NO_3-contents on flat beds decreased soon after the rainfall events. In the wet season in June, ammonium sulfate was applied to a completely saturated soil (tension < 5 kPa). Soil moisture tension increased steadily towards the end of the experiment after an initial rainfall of 65 mm on day 1. This time, ammonium could be detected in the soil for 3 weeks, indicating that nitrification was delayed.

3.3 Yields of Vegetables

Yields of Chinese cabbage and chili during the rainy season in 1994 were comparably lower than in 1993 (Table B-1). This was due to exceptionably high rainfall in 1994 (Fig. B-2). In August the whole experimental area was flooded twice. Among all vegetables tested only vegetable soybean in 1994 yielded better on flat beds than on high beds. No yield differences between cultivation systems were recorded for common cabbage in the rainy season 1992, tomato in the dry season 1992/93, and the carrot crops in the dry seasons of 1993/94 and 1995. High beds outyielded flat beds in all other crops.

Although anticipated, disorders in vegetables related to N nutrition were not severe. In Chinese cabbage, no signs of tipburn were found and incidence of internal rot was only slightly greater on flat beds than on high beds.

Table B-1 ***Marketable yield of vegetables as influenced by cultivation system (flat bed, high bed) from 1992 to 1995***

Year	1992		
Vegetable	Chinese cabbage	Common cabbage	Tomato
Cultivation system (kg/m^2)			
Flat bed	0.78 b [a]	2.15 a	4.82 a
High bed	2.15 a	2.29 a	4.88 a
Orthogonal contrast (*P*-value)			
Flat bed vs. high bed	*< 0.01*	*0.82*	*0.44*

Year	1993			1994			1995		
Vegetable	Chinese cabbage	Chili	Carrot	Vegetable soybean	Chinese cabbage	Chili	Carrot	Vegetable soybean	Chinese cabbage
Cultivation system (kg/m^2)									
Flat bed	1.37 b	0.220 b	1.29 a	1.26 a	0.75 b	0.172 b	3.06 a	0.89 b	2.43 b
High bed	2.10 a	0.616 a	1.10 a	1.10 b	1.99 a	0.364 a	3.24 a	1.31 a	3.07 a
Orthogonal contrast (*P*-value)									
Flat bed vs. high bed	*< 0.01*	*< 0.01*	*0.13*	*< 0.01*	*< 0.01*	*< 0.01*	*0.43*	*< 0.01*	*< 0.01*

[a] Means in each column followed by the same letter are not significantly different

3.4 Rating of Effects of Growth Factors on Vegetable Production

The transformation of measured data for the multiple regression analysis of vegetable yield on water stress (mean integrated soil moisture tension at the end of the cultivation of each vegetable, MISMT) and availability of soil nitrogen (mean of contents of soil nitrate during the cultivation period of each vegetable) is presented in Table B-2:

Table B-2 ***Transformation of measured data for mean integrated soil moisture tension (MISMT), mean soil NO_3 content, and net yield to percentages of the mean of four vegetables in one flat-bed plot (FB) and two high-bed plots (HB1, HB2) for the multiple regression of net yield on water stress and soil nitrogen***

	Measured data				Percentage of mean (%)		
	FB	HB1	HB2	**Mean**	FB	HB1	HB2
Vegetable soybean							
MISMT (kPa)	18.15	34.64	31.87	28.22	64	123	113
Soil N (kg NO_3-N/ha)	80	45	72	66	121	68	109
Net yield (kg/m^2)	1.34	0.96	0.94	1.08	124	89	87
Chinese cabbage							
MISMT (kPa)	4.50	4.48	8.08	5.69	79	79	142
Soil N (kg NO_3-N/ha)	24	21	21	22	109	22	96
Net yield (kg/m^2)	0.67	0.77	0.21	0.55	122	140	38
Chili							
MISMT (kPa)	14.66	14.49	14.44	14.53	101	100	99
Soil N (kg NO_3-N/ha)	35	62	36	44	80	141	82
Net yield (kg/m^2)	0.22	0.41	0.30	0.31	71	132	97
Carrot							
MISMT (kPa)	11.35	7.66	4.65	7.89	144	97	59
Soil N (kg NO_3-N/ha)	53	32	32	39	136	82	82
Net yield (kg/m^2)	3.09	2.65	3.10	2.95	105	90	105

The regression analysis gave:

$$\textbf{yield} = 152.27^{**} - 0.67^{*} \cdot \textbf{MISMT} + 0.16^{n.s.} \cdot \textbf{soil } NO_3 \ (r^2 = 0.40^{*})$$

indicating that water stress was more decisive in limiting year-round vegetable production than availability of soil nitrogen. The regression parameters can be interpreted as follows: vegetable yields decreased with greater water stress and increased when the soil contained more available nitrogen. The effect of water stress was strong as indicated by the high value of the regression parameter and statistically significant (P = 0.05). The effect of soil nitrogen was only small and statistically not significant.

4 Discussion

During the *dry season* soil nitrate accumulated (Fig. B-2). This process was observed in several tropical climates with distinct dry and rainy seasons by GREENLAND (1958). Although soil moisture is probably too low for maximum N mineralization, leaching of NO_3 is minimal in the dry season (REYNOLDS-VARGAS *et al.* 1994). Nitrate can accumulate in the surface soil by upward movement from subsoils when evaporation exceeds precipitation. Mineralization might have also been accelerated by alternate drying and re-wetting of the soil during irrigation cycles (MCLAREN & PETERSON, 1965). In the tropics, high soil temperatures favor mineralization of nitrogen during the dry season (STANFORD *et al.* 1973).

Nitrification of ammonium proceeded rapidly and completely (Fig. B-3), but soil nitrate accumulated to levels that can not be explained by lack of leaching alone, since significant mineralization of N from the low content of soil organic matter can not be expected. Although not analyzed in this study, release and subsequent nitrification of non-exchangeable, clay-fixed ammonium may be significant. It was shown that pools of mineralized, exchangeable and fixed soil ammonium are in equilibrium (DRURY & BEAUCHAMP, 1991). If the concentration of exchangeable NH_4 is depleted, fixed NH_4 can be released. Considerable amounts of nitrogen can be present in the non-exchangeable form (HINMAN, 1964; AVRDC, 1996). ALLISON *et al.* (1953), MENGEL & SCHERER (1981), and KEERTHISINGHE *et al.* (1984) showed that clay-fixed NH_4 was released when plants depleted the pool of exchangeable NH_4 by absorption. Nitrification could be another process to lower the pool of exchangeable NH_4 and thereby trigger release of non-exchangeable NH_4 from the fixing sites in clay minerals. The content of NH_4-fixing clay minerals is usually higher at greater soil depth. During the dry season, soils become aerobic to deeper layers. Exchangeable NH_4 can then be nitrified in the aerobic subsoil and, in turn, accelerate release of fixed NH_4 (Fig. B-1) to "recharge" the pool of exchangeable ammonium. Evaporation exceeds precipitation during the dry season and, therefore, nitrate can move towards the soil surface. This could help to explain the substantial accumulation of NO_3 in both topsoil and subsoil during the dry season (Fig. B-2).

During the *rainy season*, nitrification of ammonium proceeded slower (Fig. B-3). Soil water replaced soil oxygen and prevented oxidation of NH_4 which was presumably leached downwards. At greater soil depth where the content of NH_4-fixing clays is greater, this ammonium can be immobilized. It could be concluded that high

soil moisture during the rainy season was favorable for fixation of fertilizer-NH_4 to clay minerals, and low soil moisture during the dry season was a prerequisite for release of NH_4 from the fixing sites when the pool of exchangeable NH_4 was depleted by nitrification.

The described processes should have significant consequences for crop production in tropical lowlands. When soil nitrate accumulates during the dry season, this nitrogen can partially meet nitrogen requirements of vegetable crops so that additional N-fertilizer applications could be reduced. This finding can also explain the sometimes low recovery of fertilizer-N in this season (AVRDC, 1995). When the amount of native soil nitrogen is sufficient for the N-needs of vegetables, additional N from fertilizers will not be absorbed by plant roots.

Soil nitrate in and below the root zone peaked just before the onset of the rainy season. This nitrate quickly declined at the onset of rainfall. The relative importance of denitrification and leaching during transition from dry to rainy season was not traced in this study, but both processes are known to harm the environment (AVRDC, 1995). The potential loss of soil nitrate is greatest under the cropping pattern of winter vegetables followed by spring rice which is common in Taiwan's lowlands (CHIU, 1987) and other similar climates. This cropping system virtually eliminates percolation of nitrate to the groundwater (TERRY & TATE, 1980), but accelerates denitrification of NO_3. BURESH *et al*. (1993) described the role of green manure between two rice crops in immobilizing mineralized NO_3 to resist leaching, and cycling this N back to the soil N-pool so that it can be used by rice again. Green manure crops could absorb this nitrogen, protect it from loss at the onset of the rainy season, and make it available to vegetables during the rainy season when soil nitrogen is more limited. However, in highly intensive vegetable production which leaves no time and no space for green manure crops, it may be recommended to incorporate a vegetable with high N-absorption capacity as a cropping component to remove high soil nitrate contents before the onset of the rainy season. For this, a suitable vegetable should be: (1) deep rooted, (2) with high N-needs, and (3) not susceptible to excessive soil nitrogen. In the tropical lowland near Ho-Chi-Minh City in Vietnam, excessive soil nitrogen at the end of the dry season induced serious damage of Chinese cabbage by internal burn and subsequent rotting. Although shallow rooted, sweet corn would be a more suitable vegetable in this season.

Ammonium from fertilizer was nitrified slower during the rainy season (Fig. B-3).

It was anticipated that potentially greater ammonium concentrations in soil during the rainy season could harm vegetables. However, no such damage was observed for Chinese cabbage as a susceptible species. This could be attributed to a pallative effect of nitrate on ammonium injury in plants (IKEDA & YAMADA, 1984). Even small amounts of soil nitrate can be rapidly absorbed by vegetables and protect susceptible species for the negative consequences of ammonium nutrition.

N fertilizer increased nitrate contents above 30-cm soil depth in flat beds. This nitrate decreased within a few weeks after application. At the same time, yields of vegetables remained low, and soil nitrate was comparably high at 30 to 60-cm soil depth. On high beds, application of N fertilizer did not increase soil nitrate much, vegetables yielded much better, and less nitrate was found below the root zone. In Chapter A it was concluded that greater soil moisture induced shallow root systems with a relatively small rootmass in vegetables on flat beds. There is evidence that available soil nitrogen could not be effectively absorbed by crops on flat beds. Soil nitrate increased above 30-cm depth after application of N since vegetables could not absorb it. In the succeeding weeks the nitrogen that was not absorbed was easily leached out of the root zone. This could explain the greater amounts of nitrate at 30 to 60-cm soil depth in flat beds. Consequences were poor biomass production in vegetables and hence low yields. WESSELING (1974) stated that the efficiency of applied N-fertilizer depends largely on drainage conditions. On better drained high beds water stress was less. Root systems of vegetables were extensive and exploit a larger soil volume. Obviously, available soil nitrogen was absorbed efficiently so that application of N fertilizer did not result in significant increases in soil nitrate above 30-cm depth. Vegetables produced much greater biomass and yields. Therefore, less nitrate was leached below the root zone.

Overall, the direct impacts of excessive soil moisture in the rainy season and deficient soil moisture in the dry season were apparently more detrimental to vegetable growth than was limited availability of soil nitrogen. Similar findings for grain corn (ISFAN, 1984) indicate that nitrogen effects were found to be secondary when soil water stress occurred. Permanent high beds provided suitable conditions for alleviating water stress and promoting root growth in vegetables during the rainy season. This appeared as a prerequisite for higher yields, efficient utilization of N fertilizer, and prevention of environmental pollution by nitrogen.

C Effects of N Management on Vegetable Production — N_{min}-Reduced Method

1 Introduction

1.1 Demand for N Management in Vegetable Production

Vegetables require nitrogen in a substantial quantity for optimum plant growth. Considerable amounts of N are usually applied to produce economic yields of good quality. A high nitrogen concentration in plant tissues is necessary to sustain the fresh look and softness of vegetables, but an excess of N can be harmful to human health. Vegetable roots have only limited ability to absorb nutrients from the soil, hence only a part of the applied N is utilized by crops, and considerable amounts of unused N may remain in the soil. This nitrogen can create environmental hazards including leaching to the groundwater, denitrification, volatilization, eutrophication, etc. (AVRDC, 1996).

In vegetable cultivation, sources of nitrogen include the natural supply from the soil N pool, organic sources such as animal manure, plant residues or organic fertilizers, and inorganic chemical fertilizers. Since it is oftentimes difficult to assess release of nitrogen from organic sources and their recovery by crops, immediately available inorganic nitrogen from fertilizers is extremely important for vegetable production. Prices of N fertilizer are usually low compared to the price of other production factors (BOOIJ *et al.* 1993). Therefore, application of N fertilizers is often oriented towards maximizing and safeguarding of yields rather than optimum N input (NIEDER, 1983).

To reduce the detrimental impacts of excessive nitrogen on the environment, it is important to develop appropriate N management technologies to maximize the efficiency of use of N fertilizer by vegetables. Some strategies are placement of fertilizer,

timing and splitting of applications, and use of slow-release fertilizers, nitrification inhibitors, foliar applications, and fertigation (EVERAARTS, 1993*b*). Another approach to improve N management is to fine-tune the amount of N fertilizer to better synchronize soil N availability with plant requirements. Technologies include analysis of plant index-tissues and the N_{min}-method. Analysis of plant index-tissues is discussed in Chapter D.

In Central Europe, the N_{min}-method has received considerable attention. It is based upon regulating N supply according to the demand of the crop (SCHARPF & WEHRMANN, 1975; WEHRMANN & SCHARPF, 1986). Recommended application rates of N fertilizer account for the N demand of vegetable crops at specific growth stages to produce an expected yield which can vary substantially with production site. These standard N fertilizer rates are reduced by the amount of mineralized nitrogen ("N_{min}") in the effective root-zone before application, the predicted release of plant-available nitrogen from the soil, and the expected release of N from residues of preceding crops. For many vegetables, guidelines for fertilization according to this system have been established. The major objective is to prevent environmental pollution through excessive fertilizer use and thereby ensuring maximum yields and improving fertilizer use efficiency. By applying the N_{min}-method, fertilizer can be saved and leaching of nitrogen minimized (WEHRMANN, 1983; HÄHNDEL & ISEMANN, 1993). The commercial use of the N_{min}-method is, however, oftentimes limited to main crops with long growing seasons. This can be attributed to the requirement for labor and time to sample and analyze the soil (MATTHÄUS *et al.* 1994).

When standards of the N_{min}-method such as reliable estimates of N demand of vegetables and N mineralization rates of soils are lacking, more simplified N management technologies could be adopted. EVERAARTS (1993*a*) proposed to correct standard applications of N fertilizer by the amount of soil N_{min} at planting. If this technology were applied for basal N applications and side dressings of N, and coupled with simple and rapid procedures for soil analysis, a "N_{min}-reduced" method were applicable also in vegetable production in tropical lowlands. Recommendations for fertilizer application rates are usually available from the National Research Stations (NARS), farmer's associations, and other institutions.

1.2 Relevance for Vegetable Production in Tropical Lowlands

Studies of N management for vegetable production in tropical countries are limited. However, there is indication that application rates of inorganic nitrogen are alarming high and frequently exceed recommended rates several times. Some scientists (e.g. ANONYMOUS, 1973) warned of podzolization, erosion, and acidification of soils following excessive fertilization in Taiwan's agriculture.

For the cultivation of vegetable soybean, farmers usually apply as much as ten times more than the recommended fertilizer rates (HUNG *et al.* 1991). A survey undertaken in Taiwan's largest vegetable production area (Changhua county) for the crops pea, cabbage, eggplant, and Chinese chive showed that on average farmers apply fertilizers at rates up to several times (N: 132-493 %, P: 68-253 %, K: 135-284 %) greater than the recommended input (HUANG *et al.* 1989). The study showed that the originally neutral (pH 6-7) alluvial soils in this regions have changed to slightly up to strongly acidic (below pH 5.5) soil reaction, particularly in surface layers. The authors concluded that "the over-dose of fertilizer might be the main reason of soil acidification and salination". Excessive use of N fertilizer is most apparent in intensive vegetable production in the peri-urban peripheries of the big Asian cities (e.g. Katmandu; JANSEN *et al.* 1996*a* and Ho Chi Minh City; JANSEN *et al.* 1996*b*).

Increasing concern for the negative consequences of over-fertilization in tropical vegetable production has led to the demand for innovative N management practices. Studies at the Asian Vegetable Research and Development Center in Taiwan covered a wide range of technologies including balance accounts of fertilizer N input and plant recovery, residual effects of fertilizer N, placement of fertilizer N, and substitution of basal N applications by starter N solutions (AVRDC, 1995; AVRDC, 1996; MIDMORE, 1995*a* and *b*).

1.3 Objectives

The objective of this study was to evaluate a "N_{min}-reduced" method as a technology to reduce traditional N rates applied by farmers and for minimizing leaching losses of NO_3 year-round. Specific objectives were:

- To evaluate the impact of lowering standard rates of N by the amount of mineralized soil nitrogen on consumption of fertilizer N

- To determine the influence of reduced rates of N fertilizer on soil nitrogen, plant nitrogen, and vegetable yield
- To estimate reduction of NO_3 leaching by lowering application rates of N fertilizer
- To study the interactions between cultivation systems and fertilizer management on vegetable production

2 Materials and Methods

2.1 Soil Nitrogen Analysis and Calculation of the N_{min}-Reduced Fertilizer Rate

Soil samples were taken from flat beds and high beds where the standard N rate and the N_{min}-reduced rate was applied (four replications). The N application rate in the N_{min}-reduced treatment was calculated by reducing the standard N rate by the measured amount of soil NO_3 before fertilizer application. This amount was the mean of NO_3 at 0 to 30-cm soil depth in flat bed plots and high bed plots in the N_{min}-reduced treatment. Soil ammonium was not considered for calculation of the N_{min} content since NH_4 contents were usually low except soon after fertilizer application. Until transplanting of chili in July 1994, N_{min} calculations included an expected release of nitrogen from residues of the preceding vegetable. Since no release of N and no positive effect of crop residues on succeeding vegetables could be measured (Chapter E), residues were subsequently removed from the field and not included in N_{min} calculations. Experimentation started in May 1993 and was continued through September 1995. For the first two crops in 1993, Chinese cabbage and chili, the N_{min}-reduced method was only applied for basal applications of fertilizer and subsequently for both basal applications and side dressings. From November 1993 until May 1995 soil was sampled with two replications at weekly intervals. Further details of sampling and analysis of soil are described in Chapter B.

2.2 Plant Nitrogen Analysis

Analysis of nitrate in plant sap of petioles is a suitable method for assessing the N status of plants (see Chapter D). From November 1993 until May 1995, petioles were collected at weekly intervals in flat and high bed plots where the standard N rate and the N_{min}-reduced rate was applied (two replications). Petioles were collected early morning to minimize differences in cell turgidity of plants. Eight newly expanded leaves per plot of vegetable soybean and carrot, twenty complete leaves per plot of chili, and five midribs of recently matured leaves per plot of Chinese cabbage were required to obtain sufficient sap for analysis. Between sampling and analysis, petioles were stored on ice. The sap of the chopped samples was extracted with a garlic press and diluted up to fifty times with de-ionized water using a micro-pipette to fit the range (5-225 ppm NO_3) of Merck's Reflectoquant test strips.

3 Results

3.1 Contents of Soil N_{min} and Application Rates of N

A total of 1,070 kg/ha nitrogen was applied to nine vegetable crops during the 29-month cropping sequence when standard rates of N fertilizer were applied. Soil N_{min}-contents were high during the dry season and exceeded the standard N rates particularly in the crops of carrot and vegetable soybean in 1993/94. Therefore, no N fertilizer was applied to those crops (Table C-1). 470 kg/ha N or 56 % were saved by applying the N_{min}-reduced method.

3.2 Soil Nitrogen

Compared to the standard N rates (Fig. B-2), reductions in N applications due to the N_{min}-reduced method lowered soil nitrate contents in and below the root zone of vegetables throughout the season (Fig. C-1). Soil nitrate was high in the dry season and low in the rainy season. Although no N fertilizers were applied during the dry season 1993/94, soil nitrate accumulated until middle of April 1994. Application of N did not increase soil nitrate much. Nitrate contents in flat and in high beds were very similar at 0 to 30-cm and 30 to 60-cm soil depth.

Table C-1 ***Soil N_{min} contents in the N_{min}-reduced treatment (0 to 30-cm depth) and N-fertilizer schedules of vegetables cultivated with traditional rate and N_{min}-reduced rate in two cultivation systems from 1993 to 1995 (N-application rates in the N_{min}-reduced treatment were lowered by the rounded mean of soil-NO_3 in flat and high beds)***

Crop	Chinese cabbage			Chili				Carrot	
Cultivation period (week-month)	1-May to 3-Jun '93 [a]			3-Jun to 1-Nov '93				4-Nov '93 to 4-Feb '94	
Date of application (week-month)	1-May	3-May	1-Jun	3-Jun	3-Jul	2-Aug	4-Aug	4-Nov	3-Jan
N_{min}-content before fertilization									
Flat bed (kg NO_3-N/ha)	43	-- [b]	--	30	-- [b]	--	--	132	213
High bed (kg NO_3-N/ha)	60	--	--	34	--	--	--	139	37
Mean	**52**			**32**				**136**	**125**
Fertilizer application rate									
Traditional rate (kg N/ha)	60	30	30	50	50	50	50	60	60
N_{min}-reduced rate (kg N/ha)	0[3]	30	30	20	50	50	50	0	0

Crop	Vegetable soybean			Chinese cabbage			Chili		
Cultivation period (week-month)	1-Mar to 4-May '94			4-May to 3-Jul '94			3-Jul to 4-Dec '94		
Date of application (week-month)	1-Mar	1-Apr	1-May	4-May	2-Jun	4-Jun	3-Jul	4-Aug	2-Nov
N_{min}-content before fertilization									
Flat bed (kg NO_3-N/ha)	43	120	51	22	32	21	16	52	23
High bed (kg NO_3-N/ha)	16	101	20	19	39	13	20	25	21
Mean	**30**	**111**	**36**	**21**	**36**	**17**	**18**	**39**	**22**
Fertilizer application rate									
Traditional rate (kg N/ha)	20	20	20	60	30	30	50	50	50
N_{min}-reduced rate (kg N/ha)	0	0	0	20 [c]	0	0 [c]	30	10	30

Crop	Carrot		Vegetable soybean			Chinese cabbage		
Cultivation period (week-month)	2-Jan to 1-Apr '95		1-May to 3-Jul '95			3-Jul to 3-Sep '95		
Date of application (week-month)	2-Jan	4-Mar	1-May	1-Jun	1-Jul	3-Jul	2-Aug	1-Sep
N_{min}-content before fertilization								
Flat bed (kg NO_3-N/ha)	18	52	6	17	6	2	27	27
High bed (kg NO_3-N/ha)	25	48	7	16	7	6	41	20
Mean	**22**	**50**	**7**	**17**	**7**	**4**	**34**	**24**
Fertilizer application rate								
Traditional rate (kg N/ha)	60	60	20	20	20	60	30	30
N_{min}-reduced rate (kg N/ha)	40	10	10	0	10	60	0	10

[a] (week-month)
[b] N_{min}-reduced method only for basal fertilizer application
[c] N_{min}-calculation included expected N-release from crop residues of the preceding vegetable

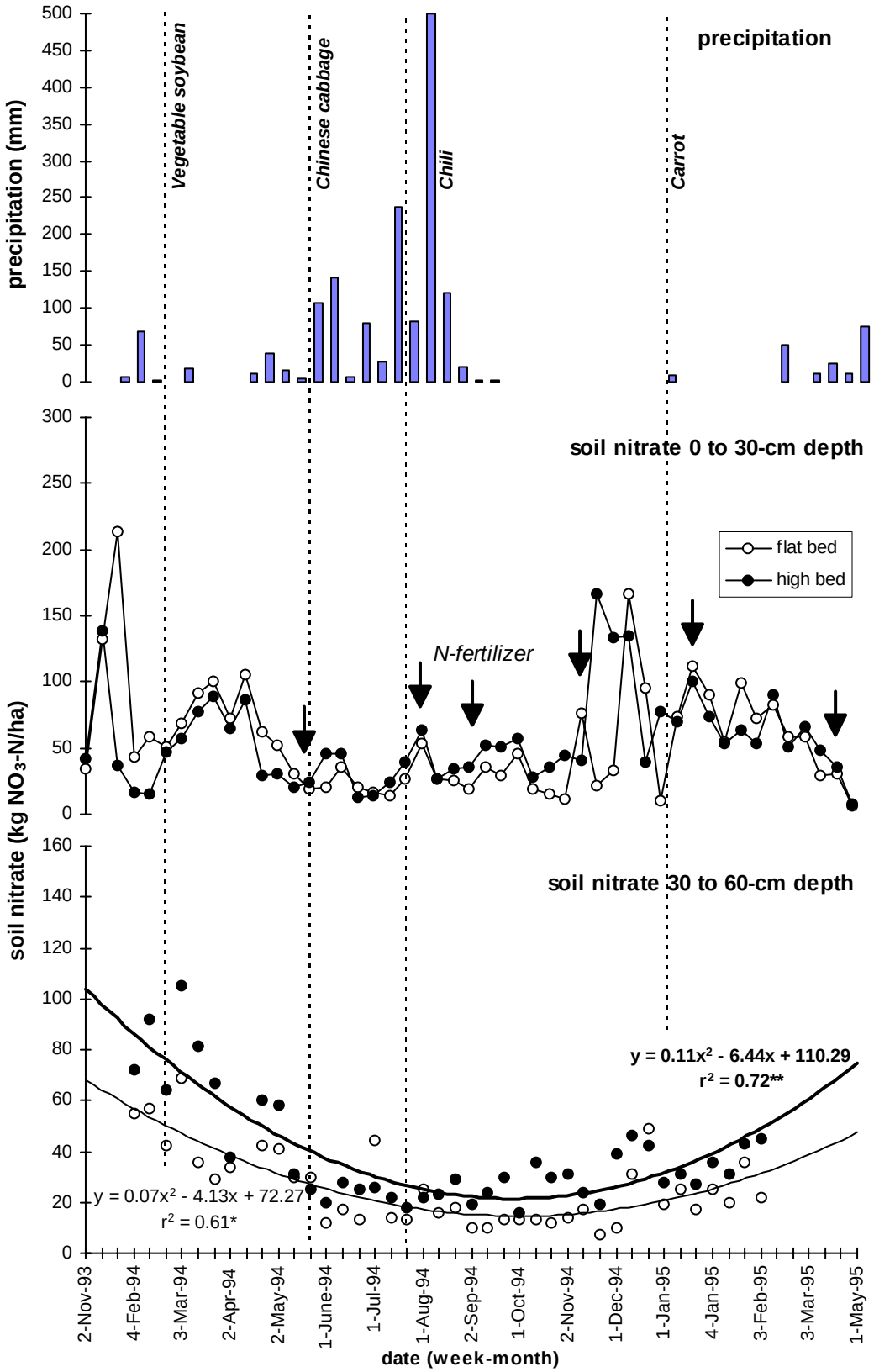

Fig. C-1 ***Weekly precipitation and soil nitrate at two soil depths in flat beds and high beds. Arrows indicate application of N-fertilizer, lines indicate quadratic trends for (thin line) flat and (thick line) high beds***

3.3 Plant nitrogen

Lower N rates in the N_{min}-reduced treatment decreased plant sap nitrate in both flat and high beds (Fig C-2). This was particularly true for Chinese cabbage. However, differences between cultivation systems were not distinct.

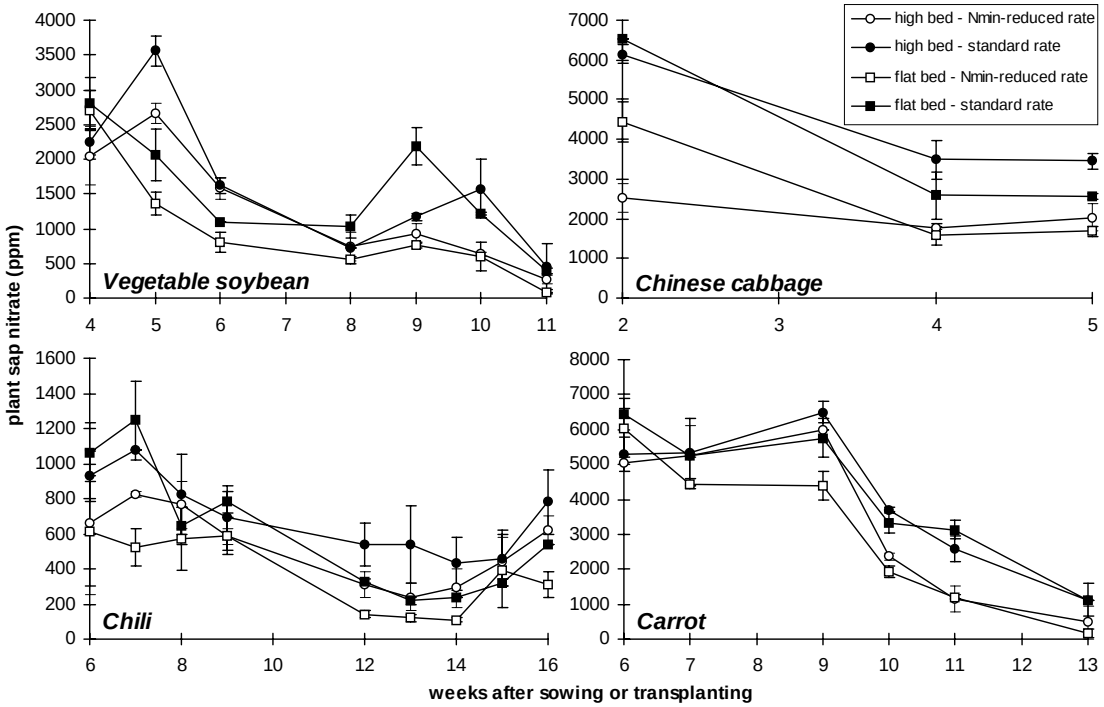

Fig. C-2 ***Concentrations of plant sap nitrate during the cultivation of vegetables in 1994/95. Error bars indicate standard errors at each sampling date***

3.4 Yields of Vegetables

Yields of Chinese cabbage and chili during the rainy season in 1994 were comparably lower than in 1993. This was due to exceptionable high rainfall particularly in August 1994 when the whole experimental area was flooded twice. Among all vegetables tested only vegetable soybean in 1994 yielded better on flat beds than on high beds (Table C-2). No yield differences between cultivation systems were recorded for common cabbage in the rainy season 1992, tomato in the dry season 1992/93, and the carrot crops in the dry seasons of 1993/94 and 1995. High beds outyielded flat beds in all other crops. Except for Chinese cabbage and chili in 1994, marketable yield of vegetables was not affected by fertilization regime on flat beds. However, on high beds, the N_{min}-reduced treatment significantly reduced crop yields for all except three crops (Chinese cabbage and carrot in 1993, and vegetable soybean in 1995).

Table C-2 ***Marketable yield of vegetables as influenced by cultivation system (flat bed, high bed) and fertilizer rate (N_{min}-reduced rate, traditional rate) 1992 to 1995***

Year	1992 [a]		
Vegetable	Chinese cabbage	Common cabbage	Tomato
Analysis of variance (kg/m^2)			
Flat bed			
Traditional rate	0.78	2.15	4.82
High bed			
Traditional rate	2.15	2.29	4.88
Orthogonal contrast (*P*-value)			
Flat bed vs. high bed	*< 0.01*	*0.82*	*0.44*

Year	1993			1994			1995		
Vegetable	Chinese cabbage	Chili	Carrot	Vegetable soybean	Chinese cabbage	Chili	Carrot	Vegetable soybean	Chinese cabbage
Analysis of variance (kg/m^2)									
Flat bed									
Traditional rate	1.37 a [b]	0.220 a	1.29 a	1.26 a	0.75 a	0.172 a	3.06 a	0.89 a	2.43 a
N_{min}-reduced rate	1.49 a	0.202 a	1.40 a	1.19 a	0.19 b	0.070 b	3.00 a	0.88 a	1.80 a
Mean	**1.43**	**0.211**	**1.35**	**1.23**	**0.47**	**0.121**	**3.03**	**0.89**	**2.12**
High bed									
Traditional rate	2.10 a	0.616 a	1.10 a	1.10 a	1.99 a	0.364 a	3.24 a	1.31 a	3.07 a
N_{min}-reduced rate	2.14 a	0.533 b	1.16 a	1.05 b	1.32 b	0.292 b	2.99 b	1.28 a	2.32 b
Mean	**2.12**	**0.575**	**1.13**	**1.13**	**1.66**	**0.328**	**3.12**	**1.30**	**2.70**
Orthogonal contrast (*P*-value)									
Flat bed vs. high bed	*< 0.01*	*< 0.01*	*0.13*	*< 0.01*	*< 0.01*	*< 0.01*	*0.43*	*< 0.01*	*< 0.01*
Traditional vs. N_{min}-reduced	*0.31*	*0.04*	*0.39*	*0.06*	*< 0.01*	*< 0.01*	*< 0.01*	*0.23*	*< 0.01*

[a] no different N-fertilizer rates in 1992

[b] Mean separation by LSD test at $P = 0.05$; means in each column followed by the same letter are not significantly different

3.5 Effect of N Management on Soil Nitrogen, Plant Nitrogen, and Vegetable Yield

The relationship between (1) nutrient application, (2) nutrient uptake, and (3) crop yield can be presented in "three quadrant" diagrams (VAN KEULEN, 1982). Those diagrams were modified to "four quadrant" diagrams to include (4) the nutrient content in the soil. In Figs C-3 and C-4, the total of N applied to each vegetable crop following the standard N rate and the "N_{min}-reduced" method substituted "nutrient application". "Nutrient content in soil" was measured as the mean of soil NO_3 content during the cropping period, and the mean of plant sap NO_3 concentration during the cropping period substituted for "nutrient uptake".

The standard N application rate increased soil nitrate more on flat beds than on high beds (Figs C-3 and C-4, quadrant *a*). This was particularly pronounced during the rainy season when Chinese cabbage and chili were cultivated: soil nitrate was similar in flat and high beds when the "N_{min}-reduced" rate was applied, but much greater in flat beds when the standard N rate was applied. The N fertilizer rates were reflected in plant sap nitrate (Figs C-3 and C-4, quadrant *b*): plant sap NO_3 was greater when more N fertilizer was applied. However, the greater contents of soil NO_3 in flat beds did not much increase plant sap nitrate in vegetables. This was particularly apparent in the rainy season: during chili (Fig C-4) soil nitrate averaged at 40 kg N/ha when the "N_{min}-reduced" fertilizer rate was applied, and at 100 kg N/ha when the standard rate was applied. Although soil nitrate content was so different, plant sap nitrate was similar (600 ppm and 750 ppm) in both treatments. The same was true for Chinese cabbage (Fig. C-3). Greater plant sap nitrate was connected with better yields of vegetables (Figs C-3 and C-4, quadrant *c*). However, this effect was minimal during the dry season when vegetable soybean and carrot were cultivated. During the rainy season, greater plant sap nitrate was related to better crop yields when those yields were at a marginal level (chili on flat beds, Fig. C-4). Differences in yields were much more due to the cultivation system than to plant sap nitrate (Figs C-3 and C-4, quadrant *c*) and N application rate (Figs C-3 and C-4, quadrant *d*).

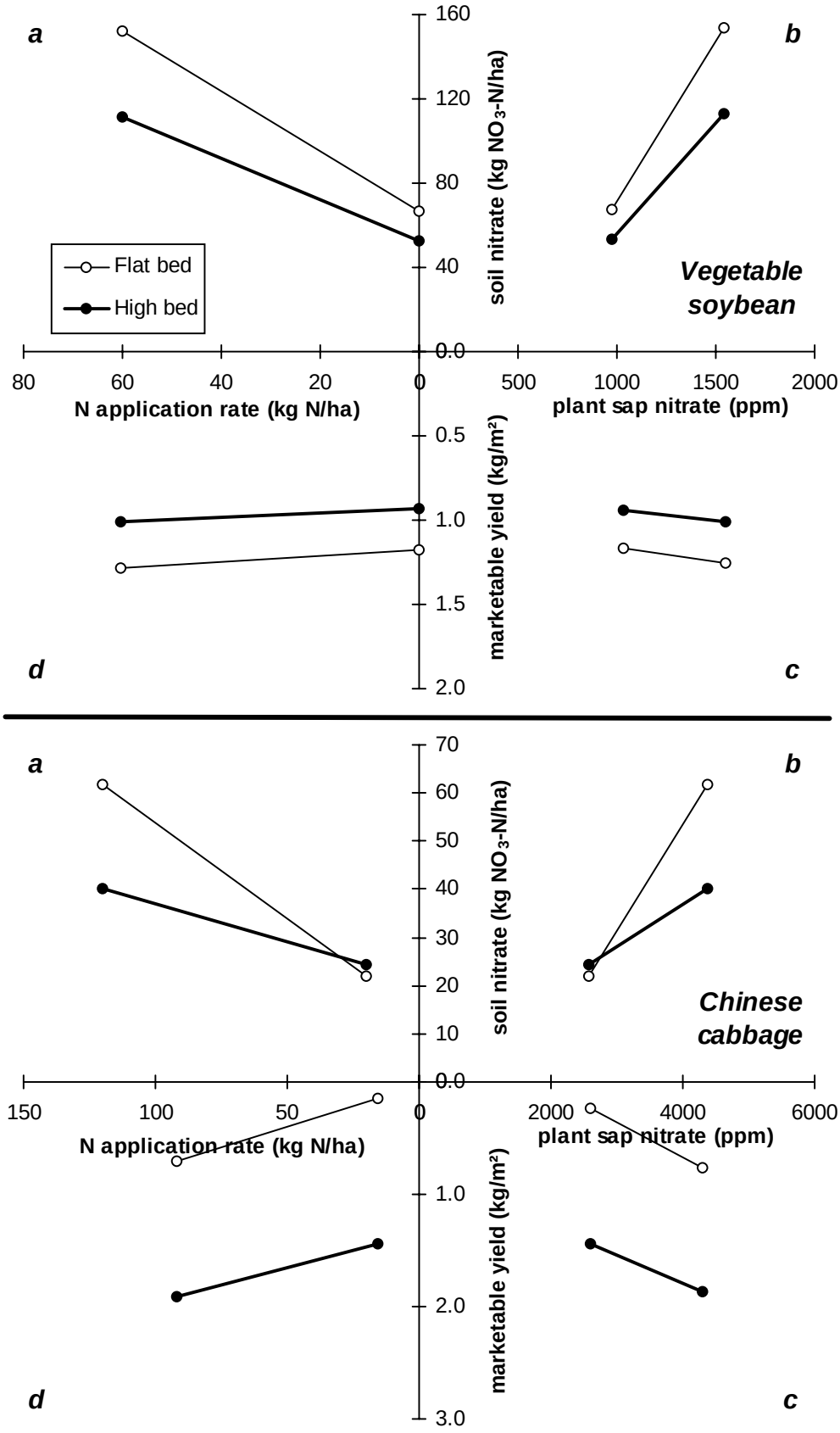

Fig. C-3 ***Effect of cultivation systems and N fertilizer rates on (a) soil nitrate and (b) plant sap nitrate, with (c and d) corresponding yield of vegetable soybean and Chinese cabbage in 1994***

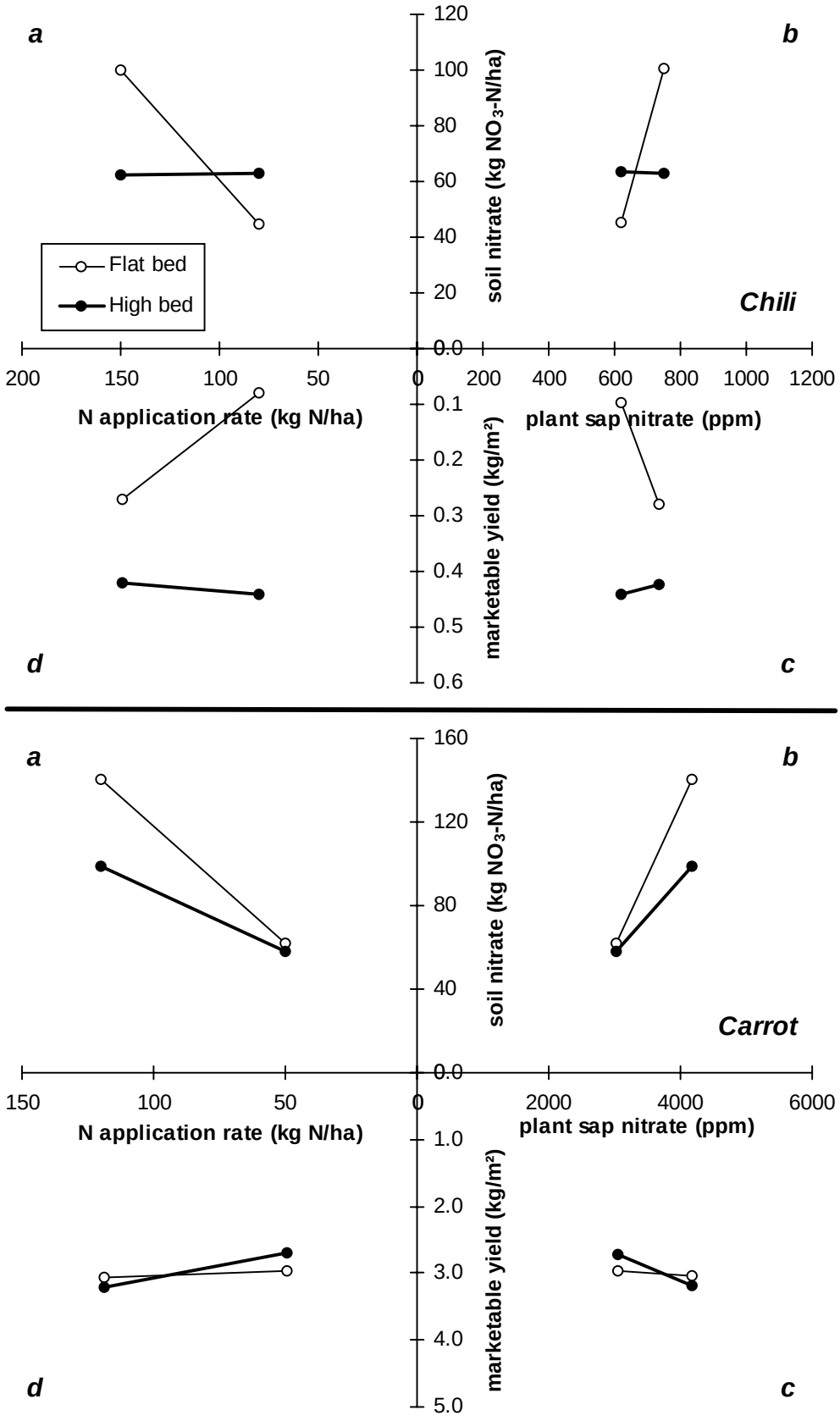

Fig. C-4 ***Effect of cultivation systems and N fertilizer rates on (a) soil nitrate and (b) plant sap nitrate, with (c and d) corresponding yield of chili and carrot in 1994/95***

4 Discussion

Adherence to the "N_{min}-reduced" method as a tool for N management considerably lowered the amounts of N fertilizer applied. On traditional *flat beds*, reduction of N rates negatively affected vegetable yields only in the rainy season in 1994. Yields of Chinese cabbage and chili were significantly reduced, but only from a marginal level. The success of the N_{min}-reduced method on flat beds could be attributed to the effect of seasonal variations in soil moisture on soil nitrogen. In the *dry season*, soil nitrate accumulated and largely obviated the need for additional N fertilizer. In 1994 soil nitrate accumulated although no N fertilizer was applied (Fig. C-2). This hints at the possible release of nitrogen from N-fixing clay minerals as discussed in Chapter B. During the *rainy season*, greater contents of soil nitrate were not reflected in appreciably greater concentrations of nitrate in plant sap. In Chapter A it was concluded that water stress developed more readily on flood-prone flat beds. Soil water plays an important role in the recovery of soil nutrients by its effect on soil oxygen (BRAUN & ROY, 1983). Anaerobic conditions inhibit the active processes of the root system and thereby inhibit uptake and transport of nutrients (JACKSON & DREW, 1984). Obviously, overwet soil conditions limited the ability of root systems of vegetables on flat beds to effectively absorb available soil nitrogen. This process was accelerated by the shallow root depth and the small rootmass (SØRENSEN, 1993). When the standard N rate was applied, the nitrogen that could not be absorbed by vegetables remained in the soil and was subject to quick loss after rainfall. Figure B-2 revealed that soil nitrate rapidly increased after application of the standard N rate on flat beds, and leveled off soon after (Fig. B-2). At the same time, more nitrogen was leached below the root zone. When the "N_{min}-reduced" fertilizer rate was applied, application of N did not increase soil nitrate much (Fig. C-1). Less nitrate was leached below the root zone and yields were not significantly reduced, except two crops. The "N_{min}-reduced" fertilizer rate was sufficient to maintain the potential of biomass production and yield of vegetables on flat beds. Similar findings with the N_{min}-method for vegetable farming in Germany (CLAUS, 1983; WEHRMANN & SCHARPF, 1989; HÄHNDEL & ISEMANN, 1993) confirm these results.

High beds successfully alleviated the negative impact of overwet soil conditions in the rainy season. The rootmass of vegetables on those beds was greater than on flat

beds. The deeper rooted plants could exploit a larger soil volume. Available nitrogen was efficiently absorbed by vegetables and productivity was kept high throughout the season. Therefore, the higher application rate of fertilizer N did not result in greater amounts of soil nitrogen in and below the root zone. Under the improved conditions of high beds, the N rates following the "N_{min}-reduced" method were not sufficient to maintain maximum yields of vegetables. Yields were reduced in all but three crops. Even the standard N rates may not have been sufficient for maximum yields since rates were tailored to the specific production conditions of flat beds. How concentrations of nitrate in plant sap reflected deficient N nutrition of vegetables is discussed in Chapter D.

It can be concluded that N management for vegetables in tropical lowlands must follow the potential for biomass production and yield. This potential may be limited by growth factors (e.g. soil water) other than nitrogen under certain production conditions (e.g. flat beds).

D Effects of N Management on Vegetable Production — Integrated Analysis of Soil and Plant Nitrogen

1 Introduction

1.1 Plant Analysis for N Management in Vegetable Production

Fertilizer-recommendation programs like the N_{min}-method are based on soil testing results. However, the nutrient content in soil may not be the best indicator of plant requirements and yield. Therefore, a better measure of the nutrient status of plants is required. It has long been recognized that relationships exist between nutrient concentrations in plant tissues and yield (SMITH, 1986). Plant analysis was suggested as a suitable technique for assessing the nutrient status of crops. This status can then be used for diagnosing nutrient deficiencies for predicting yields and fertilizer requirements.

Techniques for analysis of plant N as a tool to adjust N fertilizer rates to requirements of crops should be sensitive, simple, quick, and inexpensive. This is particularly true in production of vegetables to which fertilizers are usually applied several times during their short growth cycle. Techniques for laboratory analysis of N in plant tissues are readily available, but the costs and time lag between sampling and result have limited the commercial use of those standard methods (HARTZ *et al.* 1993). Therefore, on-farm quick tests for (1) a specific form of N in (2) plant index-tissues were proposed.

(1) When analyzing complete leaves of vegetables, NO_3-N was a better measure of plant N status then total N (EL-SHEIKH & BROYER, 1970).

(2) When supply of nutrients to plants becomes limited, nutrient concentrations decline most quickly in rapidly expanding tissues. Petioles or midribs of leaves act as a storage and transport organ for nitrate. Therefore, petioles or midribs of younger leaves are a sensitive indicator for plant N status and N nutrition of plants (SCAIFE & STEVENS, 1983). It was shown that analysis of NO_3-concentration in sap of petioles of recently matured leaves is superior to measuring NO_3 in complete leaves (PRASAD & SPIERS, 1984).

1.2 Integrated Analysis of Soil and Plant Nitrogen for N Management

Comparing the virtues of plant sap analysis with soil analysis for N management is not useful. Plant N status depends on the availability of nitrogen in the soil. Therefore, pooling information from both sources may be a more effective technique to manage N fertilization. It was shown that the analysis of NO_3 was more accurate to indicate availability of soil N to plants than other procedures (MAGDOFF *et al.* 1984). Therefore, soil nitrate should be related to plant sap nitrate, and to crop yield. Difficulties in interpreting soil and plant nitrogen for estimating yield response in vegetables include: (1) the variability over time and site, and (2) the biological validity of mathematical models applied.

(1) Fluctuating NO_3-concentrations reveal the need for periodic measurement of the course of NO_3-concentrations in soil and plant through time (ALT & FÜLL, 1988). MAIER *et al*. (1994) highlighted the need for site-specific calibration of published diagnostic standards. For these reasons, the calibration of the method poses the most significant hindrance to practical application since standards for soil N contents and critical NO_3-N concentrations in plant sap are still lacking (BEVERLY, 1994).

(2) Analysis of dependencies between soil nitrogen, plant nitrogen, and crop yield are usually aimed at defining critical nutrient concentrations or critical nutrient ranges (DOW & ROBERTS, 1982). Applied functional relations for determining these limits range from more theoretical response curves (EL-SHEIKH & BROYER, 1970), over biologically meaningless quadratic or cubic regressions, to more valid linear-plateau models (WESTCOTT *et al.* 1991), or preferably the Michaelis-Menten model of saturation kinetics (WESTCOTT *et al.* 1994).

1.3 Objectives

The objective of this study was to evaluate an integrated analysis of soil and plant nitrogen as a technology to adjust N fertilizer application to real-time N needs of vegetables. Specific objectives were:

- To determine a biologically valid mathematical model to interpret the relationship between (1) soil nitrogen and plant nitrogen, and (2) soil nitrogen and yield
- To apply the model to vegetable production in a controlled glasshouse environment and under field conditions in tropical lowlands
- To estimate the value of the technology for vegetable production in tropical lowlands

2 Material and Methods

2.1 Experiments

To determine a mathematical model for interpreting the relations between soil and plant nitrogen, and vegetable yield, a *glasshouse experiment* was conducted. From November to December 1994, Pak Choi (*Brassica chinensis* L.; cv. "San-Feng", Known You Seed Co.) was grown at 6×6-cm interplant spacing in boxes 60 cm long, 50 cm wide, and 30 cm deep (80 plants per box). Before sowing, soil was collected from an AVRDC field and residual soil nitrate leached by flooding boxes with water on three successive days until the leachate contained less than 25 ppm NO_3. Six nitrate rates (0, 50, 100, 150, 200, and 250 kg N/ha) were evenly split over four weeks and applied as potassium-nitrate early in a week. Treatments in the completely randomized one-factorial experiment were replicated twice. The crop was harvested at the end of week 4.

To estimate the value of an integrated analysis of soil nitrogen, plant nitrogen and yield for vegetable production in tropical lowlands, the model was applied to the *field experiments* (Chapter II). Those data were derived from crops of vegetable soybean, Chinese cabbage, and chili in 1994, and from carrot and vegetable soybean in 1995.

2.2 Soil and Plant Nitrogen Analysis

In the *glasshouse experiment*, soil was sampled with a 7 mm-diameter auger to the full depth of boxes at the end of each week (five samples per box). Three midribs of recently matured leaves of Pak Choi were sampled per box and week. In the *field experiments*, soil and plant samples were collected and analyzed for nitrate as described in Chapters B and C. For carrot and vegetable soybean in 1995, samples were collected from 56 plots 11 (carrot) and 4 (vegetable soybean) weeks after sowing.

3 Results

3.1 Relating Plant Nitrogen to Soil Nitrogen, and Yield to Soil Nitrogen

The Michaelis-Menten model assumes that the speed of an enzyme-catalyzed decomposition of a substrate depends entirely on the quantity of substrate if the concentration of the enzyme is kept constant (GEISSLER *et al.* 1981). From this assumption it follows that increasing a low substrate concentration will result in an rapid increase in decomposition rate since the enzyme is incompletely saturated. The maximum activity is attained when an enzyme saturation is achieved, and any further increase in substrate concentration is without effect on the rate. This relationship can be expressed in the Michaelis-Menten equation as follows:

$$V = \frac{V_{\max} \cdot S}{K_m + S}$$

where: V is the decomposition rate (speed), $V_{\max}$ represents the maximum decomposition rate, S is the substrate content, and K_{m} represents the dissociation constant (Michaelis constant).

K_{m} is equal to the substrate content S when the decomposition rate V equals ½ $V_{\max}$. Thus, the substrate content at which the half-maximum speed of decomposition is attained is a characteristic constant of this reaction and can be interpreted as the inverse of enzyme-substrate affinity (Fig. D-1).

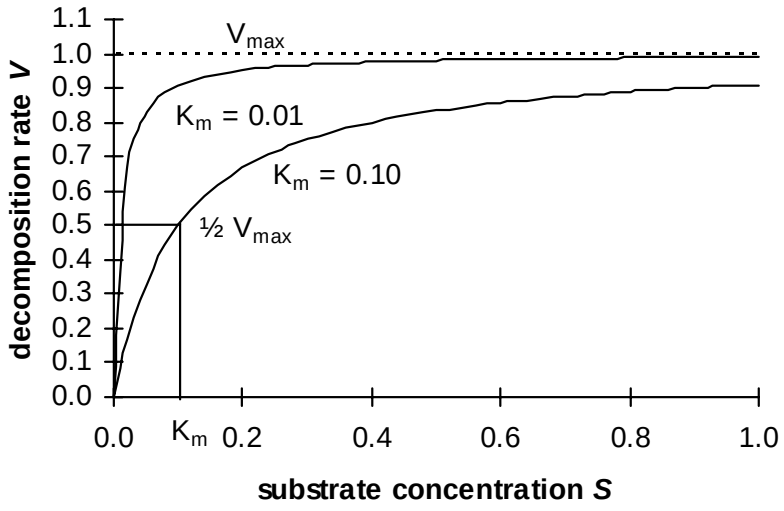

Fig. D-1 ***The Michaelis-Menten curve as affected by the dissociation constant K_m (V_{max} = 1)***

If this theory is applied to nitrate uptake by plants (WESTCOTT *et al.* 1994), sap NO_3 concentration substitutes decomposition rate (V), saturation concentration of sap NO_3 substitutes maximum decomposition rate (V_{max}), soil NO_3 content substitutes substrate concentration (S), and the inverse of affinity for soil NO_3 substitutes the dissociation constant (K_m).

3.2 Glasshouse Experiment

Response to the different N-application rates was clearly reflected in soil nitrate and plant-sap nitrate (Fig. D-2). Plant-sap nitrate slightly decreased for most of the treatments from 3 weeks after sowing (WAS) to 4 WAS despite increases in soil nitrate. Soil nitrate was much higher in treatments receiving 200 and 250 kg N/ha. However, after week 2, plant-sap nitrate concentration in these treatments was not different from treatments with only 100 and 150 kg N/ha. The same was reflected in yields: there were no significant differences between treatments receiving 100 kg N/ha or more (Table D-1).

The relationship between soil nitrate and sap nitrate measured 1 WAS was linear and followed Michaelis-Menten kinetics in succeeding weeks (Fig. D-3). All regressions were highly significant (Table D-2). Affinity for soil nitrate increased towards

Table D-1 ***Nitrogen fertilizer rates and fresh weight at harvest of Pak Choi in the glasshouse experiment in 1994***

Nitrate application rate (kg NO_3-N/ha)	Fresh weight (g/plant)
0	1.70 c [a]
50	9.65 b
100	15.56 ab
150	16.11 ab
200	16.70 ab
250	19.52 a

[a] Mean separation by LSD test at $P = 0.05$. Means followed by the same letter are not significantly different

crop maturity as indicated by decreasing estimates for K_m. The relationship yield = f (soil nitrate) was not clearly influenced by crop age (Fig. D-3) and all estimates for maximum yield were around 20 g/plant (Table D-2).

The "optimum" fertilization strategy for Pak Choi in this experiment follows from Table D-1, and Figs D-2 and D-3. Yield (15.56 g/plant) at a total N rate of 100 kg N/ha was statistically not different from the maximum yield (19.52 g/plant) at 250 kg N/ha, but yield (9.56 g/plant) at 50 kg N/ha was significantly lower (Table D-1). Therefore, the optimum total N rate was between 50 and 100 kg N/ha, or when split evenly over the cultivation period of four weeks approximately 15 to 20 kg N/ha·week. At this rate, the vegetable was able to absorb all nitrogen applied, and soil nitrate did not accumulate to levels above 10 kg NO_3-N/ha (Fig. D-2). When more fertilizer N was applied, this surplus N was not absorbed by plants indicated by no significant increase in sap nitrate. Consequently, nitrogen accumulated in the soil. The approximated "optimum" concentration of NO_3 in plant sap at an application rate of 50 to 100 kg N/ha was 1,000 ppm at 1 WAS, 3,500 ppm at 2 WAS, and around 7,500 ppm at 3 and 4 WAS (Figs D-2 and D-3). The "optimum" yield at this N rate was slightly below 15 g/plant (Fig. D-3).

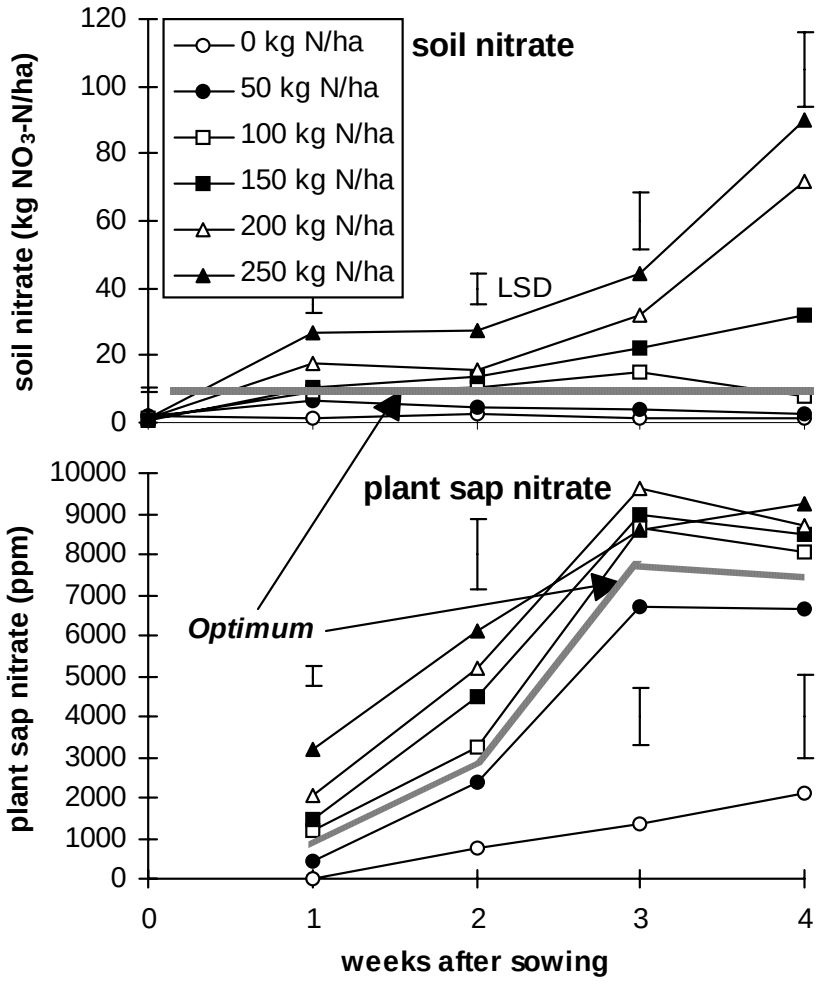

Fig. D-2 ***Soil nitrate and plant-sap nitrate in Pak Choi as affected by fertilizer-N rates in the glasshouse experiment in 1994. Error bars represent least significant differences at P = 0.05 for each sampling date***

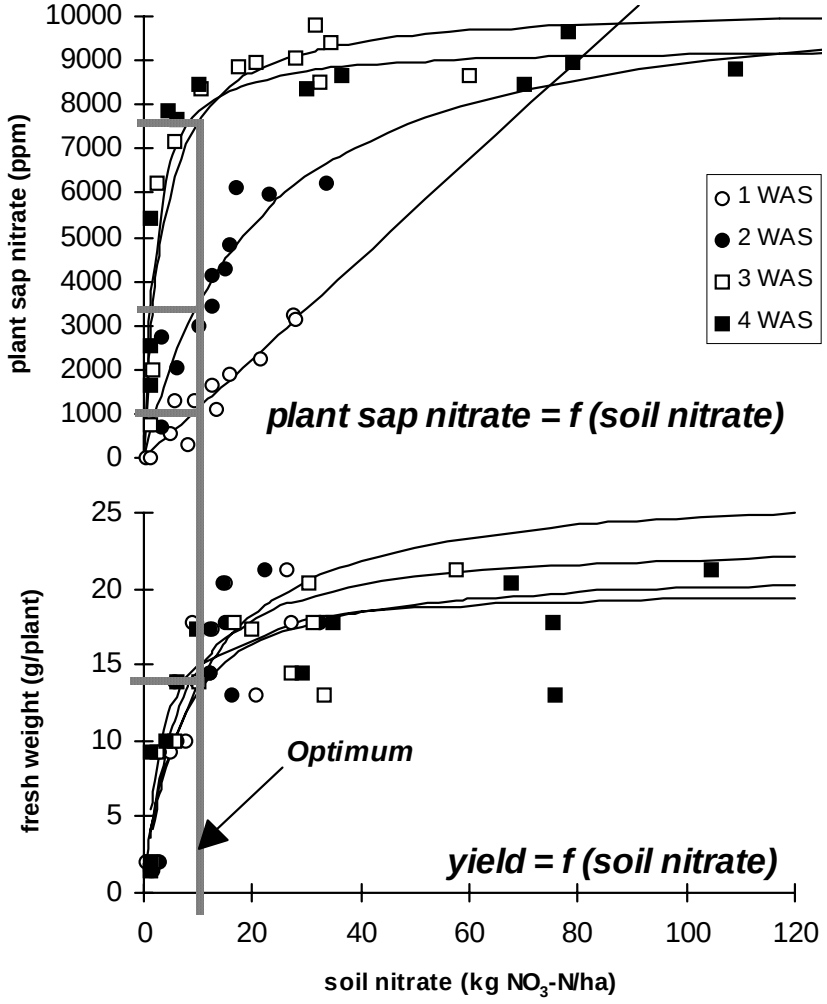

Fig. D-3 ***Relationship between sap nitrate and soil nitrate, and between yield and soil nitrate in Pak Choi in the glass-house experiment in 1994***

Table D-2 ***Parameters (± standard error) and coefficient of determination (r^2) of regressions of plant sap nitrate on soil nitrate and yield on soil nitrate of Pak Choi in the glasshouse experiment in 1994***

WAS	V_{max} ± SE [a]	K_m ± SE	r^2
	Plant sap nitrate = f (soil nitrate)		
1	Y = 29.31 ± 1.59 × X [b]		0.91** [c]
2	10790 ± 2637	19.98 ± 8.85	0.87**
3	10240 ± 671	3.33 ± 1.03	0.87**
4	9316 ± 492	1.84 ± 0.52	0.84**
	Yield = f (soil nitrate)		
1	23.13 ± 3.69	5.72 ± 2.86	0.81**
2	27.07 ± 5.38	9.61 ± 4.65	0.81**
3	21.25 ± 2.21	6.07 ± 2.46	0.85**
4	18.96 ± 1.58	3.32 ± 1.35	0.79**

[a] SE: standard error; [b] linear regression; [c] significant at $P = 0.01$

3.3 Field Experiments

When nitrate data for all measurements were pooled, hyperbolic-type regressions of plant sap nitrate on soil nitrate were statistically significant, but the fit was not very close since levels of determination were not greater than 0.58 (Fig. D-4, *left*; Table D-3). The best agreement was achieved in Chinese cabbage: calculated upper limits of plant-sap nitrate (V_{max}) were distinctly higher than realized plant NO_3 concentrations indicating insufficient N-supply from the soil.

Table D-3 ***Parameters (± standard error) and coefficient of determination (r^2) of the hyperbolic regression of plant-sap nitrate on soil nitrate of vegetable crops in the field experiments in 1994/95***

	Plant sap nitrate = f (soil nitrate)		
Vegetable	V_{max} ± SE [a]	K_m ± SE	r^2
Vegetable soybean 1994	3226 ± 461	75.39 ± 24.44	0.35** [b]
Chinese cabbage 1994	10420 ± 2396	72.11 ± 26.89	0.58**
Chili 1994	1214 ± 155	57.44 ± 14.96	0.36**
Carrot 1995	6486 ± 703	30.86 ± 10.65	0.29**

[a] SE: standard error; [b] significant at $P = 0.01$

Regressions of sap nitrate on soil nitrate at individual sampling dates (Fig. D-4, *right*) did not fit the data well (regression equations not shown) since only a limited number of samples was analyzed. However, affinity for soil nitrate increased with crop age as shown for Pak Choi in the glasshouse experiment.

In 1995, soil and plant nitrate data were collected in the carrot crop under dry season conditions (11 WAS). Fertilizer treatments were reflected in plant sap nitrate (Fig. D-5), but neither soil nitrate nor plant sap nitrate could explain variations in yield. Therefore, nitrogen was not a growth-limiting factor. In contrast to the soybean crop in the dry season in 1994 (Fig. D-4), calculated saturation concentrations of sap nitrate were much greater than those realized in vegetable soybean during the rainy season in 1995 (Fig. D-5). Neither soil nitrate nor plant-sap nitrate could explain yield differences. However, yields were distinctly lower in flat beds than in high beds although soil and plant nitrate was not much different.

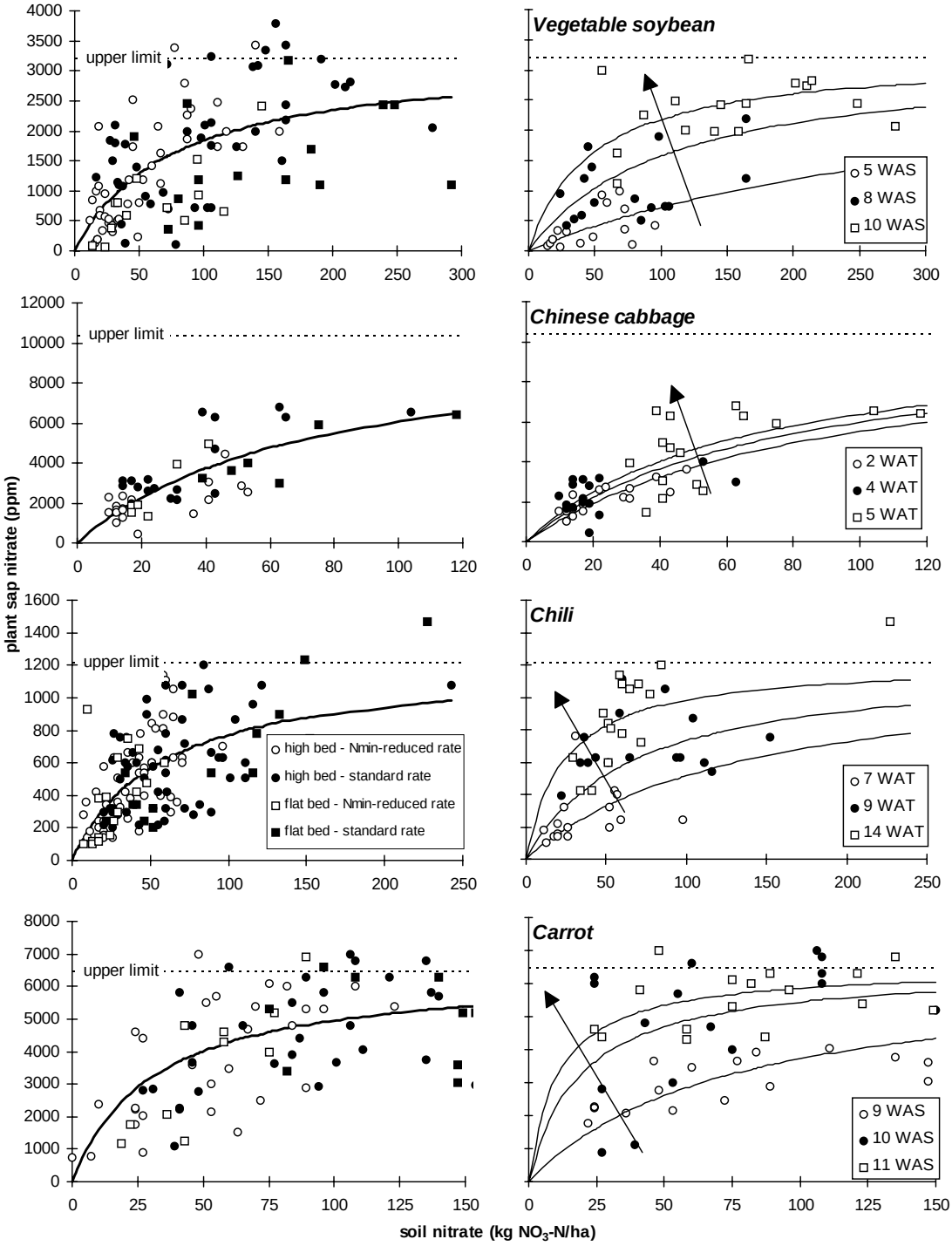

Fig. D-4 ***Relationship between plant sap nitrate and soil nitrate in four vegetables in the field experiments in 1994/95: (left) pooled analysis over all sampling dates, (right) analysis at selected individual sampling dates***

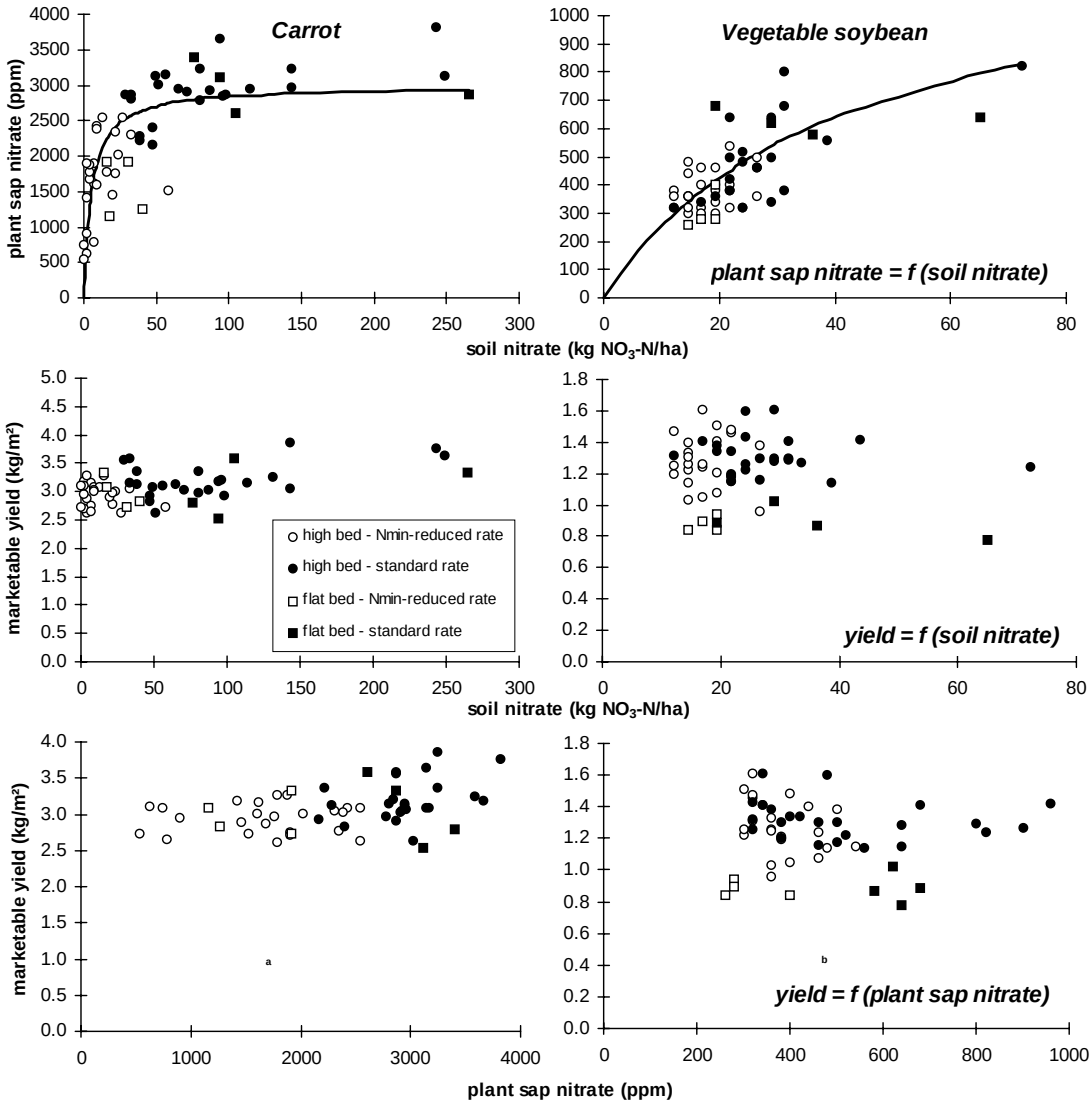

Fig. D-5 ***Relationship between plant sap nitrate and soil nitrate, marketable yield and soil nitrate, and marketable yield and plant-sap nitrate in two vegetables in the field experiment in 1995***

4 Discussion

Results in the *glasshouse experiment* with Pak Choi confirmed the usefulness of the Michaelis-Menten model of saturation kinetics in relating plant sap nitrate to soil nitrate. Hyperbolic regression of nitrate data yields two parameters, one (V_{max}) estimating a saturation level, and the other (K_m) the inverse of "affinity" (responsiveness of plant sap nitrate to soil nitrate). In contrast to a similar study on potato and peppermint by WESTCOTT *et al*. (1994), the relationship between sap and soil nitrate changed with Pak Choi crop age. Sampling early in the growth period resulted in a linear-type relationship between soil NO_3 and sap NO_3 compared to later in season, when relationships were hyperbolic with steep slopes in the range of low soil nitrate contents (Fig. D-3). NO_3 affinity increased towards crop maturity expressed by decreasing estimates for K_m. Limited ability of crops to absorb available soil N in the seedling stage can be attributed to small root volumes in this crop stage. This highlights the usefulness of starter N solutions applied close to the root system to substitute basal N applications in transplanted vegetables (AVRDC, 1995). When root mass occupied a larger volume of soil, the capacity to absorb soil nitrogen increased in Pak Choi.

Plant-sap nitrate decreased towards the end of the cultivation period. This frequently observed decline of N concentrations in plants has been explained by a depletion of soil N and translocation of N from vegetative plant parts to developing storage or reproductive organs (MAYNARD *et al.* 1976). That sap nitrate also decreased in leafy Pak Choi could be due to other physiological or metabolic processes (JARRELL & BEVERLY, 1981) in vegetative crops.

Measuring nitrate in soil and plant sap made it possible to determine the optimum fertilizer rate at which yields and efficiency of fertilizer use was maximal. Greater application rates only resulted in luxury N-consumption (BLACKMER & SCHEPERS, 1994) without further increase in yield, but to accumulation of soil nitrate. Under field conditions, this nitrate will be subject to loss (Chapter B).

The "optimum" concentration of NO_3 in plant sap changed greatly during the growth period (Fig. D-3). This stresses the need to relate sap NO_3 concentrations to plant age (PRITCHARD *et al.* 1995) rather than defining a general N accumulation level (WESTCOTT *et al*. 1994). However, since the affinity for soil nitrate changes with crop

age, it is difficult to determine how much fertilizer N has to be applied for increasing a *deficient* nitrate concentration in plant sap. In early crop stages, more fertilizer N is required to raise deficient plant sap nitrate given traditional application methods since affinity for soil nitrate is low (Fig. D-3). At later growth stages, comparably less nitrogen is required to raise deficient plant sap nitrate since affinity for soil nitrate in the range of low soil nitrate content is high.

Demonstrated changes in the relationship between soil and plant sap NO_3 may be true for many vegetables. In the *field experiments*, affinity for soil NO_3 increased towards crop maturity for all crops studied although the fit of the hyperbolic regressions was not very close (Figs B-4 and B-5). Plant sap nitrate concentrations were higher in leafy vegetables than in the other vegetables. PRITCHARD *et al*. (1995) interpreted NO_3-concentrations around 10,000 ppm as adequate to excessive in lettuce. Data from Pak Choi in the glasshouse experiment and Chinese cabbage in the field experiments suggest that this level could have wider application as a nitrate-saturation concentration for many leafy vegetables. How this concentration compares with a safe nitrate level for human consumption should not be discussed here.

Plant sap nitrate and soil nitrate data could not explain variations in crop yield (Fig. D-5). Only in Chinese cabbage during the rainy season in 1994, plant sap nitrate was much less than calculated saturation concentrations (Fig. D-4), indicating inadequate N nutrition. Serious difficulties arise with analysis of soil and plant nitrogen data to establish diagnostic criteria for N when other environmental factors inhibit crop growth apparently more than nitrogen. BEVERLY (1994) was unable to determine diagnostic criteria for potassium in sap of tomato seedlings since other factors limited growth more than the element under study. Highly significant yield differences between flat and high beds in vegetable soybean during the rainy season in 1995 were neither due to differences in soil nitrate nor to differences in plant sap nitrate (Fig. D-5). In Chapter A, yield differences were attributed to different levels of stress caused by overwet or overdry soil conditions in those cultivation systems. In Chapter B it was concluded that water stress was more detrimental to vegetable production than limited availability of nitrogen. Data for asparagus (GARDNER & ROTH, 1989) illustrate a similar phenomenon: reductions in yield resulted from suboptimal water application rates despite sufficient sap N concentrations throughout the season. Such

conditions limit the use of integrated analysis of soil and plant sap nitrate as a tool to manage N fertilization.

Authors have stressed the need for local validation of diagnostic standards of soil and plant nitrate since they encountered site-specific crop responses (MAIER *et al.* 1994). BAIRD *et al*. (1962) stressed the need to define environmental conditions before using plant analysis data to predict fertilizer requirement for crops. It could, however, be argued that those differences in response were due to growth factors which limited crop performance more than insufficient nitrogen. This explains why application rates of fertilizer N can be dramatically reduced without affecting yields when it is known that other factors limit vegetable growth more than N (Chapter C). However, yields of vegetables in tropical lowlands must be increased. Therefore, stresses caused by growth-factors other than nitrogen must be eliminated first. Only under improved field conditions, better N management can be achieved.

E Effects of Crop Residue and Green Manure Management on Vegetable Production

1 Introduction

1.1 Organic Manuring in Vegetable Production

One attempt to maintain a high level of productivity, but protect natural resources from further degradation in vegetable production is to consider organic manuring technologies to support and particularly even substitute inorganic fertilization. Organic manures include crop residues, animal manure, industrial by-products, composts, and green manure. Major difficulties in the management of organic fertilizers are the variable contents of nutrients and their availability to vegetables, sufficient supply, distance from suppliers, and availability of technical equipment for transport and application. Besides that, accurate timing of a sufficient quantity of manure means considering manure material, crop, soil, and climatic conditions (KELLY, 1990).

1.2 Crop Residues and Green Manure in Vegetable Production

Crop residues are widely regarded an integral part of vegetable production, primarily to conserve soil resources, e.g. by maintaining soil structure and organic matter. Secondarily, they can contribute to the nutrition of vegetables. Substantial amounts of residues are produced on vegetable farms and are, therefore, close at hand (FRITZ *et al.* 1989).

Several approaches were designed to include *green manure* in vegetable systems (SARRANTONIO, 1992). Amongst these options are the inclusion of green manure

crops into a vegetable cropping sequence as a pre- or succeeding crop, as a relay-intercrop, or as a full intercrop (Fig. E-1). Green manure may also be produced away from the production area, and applied as a mulch (YIH, 1989), but more likely the green manure is grown as a full intercycle crop in the field, or as a strip or alley besides the field (SITOMPUL *et al.* 1992).

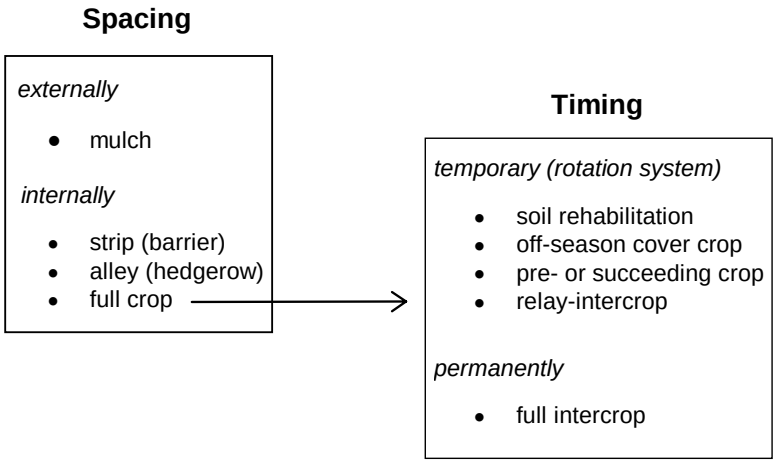

Fig. E-1 ***Inclusion of green manure in vegetable production***

Intercropping green manure crops as living mulches in between the cash crop is particularly interesting where limitations to the cropping area drastically reduce the scope for rotations with green manure (AKOBUNDU & OKIGBO, 1984). Most such research has been done for field crops and few investigations have been conducted for vegetables. The latter were aiming at (1) controlling pest incidence, and (2) improving soil conditions:

(1) For pest control, BUGG *et al.* (1991) intercropped cantaloupes with several cover crops and ANDOW *et al*. (1986) cultivated cabbage with live mulch.

(2) NICHOLSON & WIEN (1983) screened a number of turfgrasses and clovers for their possible role in sweet corn and cabbage. WILES *et al.* (1989) investigated a living mulch system of Pak Choi with rygrass. SARRANTONIO (1992) discussed relay-intercropping schemes of tomato with hairy vetch, cereal rye, and annual rygrass. ILNICKI & ENACHE (1992) intercropped several vegetables with subterranean clover.

Usually, these studies detected significant competition between live mulch and vegetable. Therefore, WILES *et al.* (1989) and SARRANTONIO (1992) highlighted the need to suppress mulch growth to minimize competition with vegetables, and LANINI *et al.* (1989) found that possible positive effects of a live mulch are likely to be offset by direct competition.

1.3 Use of Crop Residues and Green Manure in Tropical Lowlands

The need for improvement of soils in tropical lowlands is clear since organic matter content is usually low. In rice-based environments, long-term wet plowing (puddling) has created a degraded, single-grained structure of surface soils on top of a hard plow pan in the compacted subsoil (ISHII, 1986). Management of crop residues and green manure may have the potential to improve soil organic matter and soil structure and may contribute to the nutrition of vegetables.

However, incorporation of *fresh organic materials* can exert potentially detrimental effects. Externally added organic matter to flooded rice soils can accelerate soil reductive conditions by oxygen consumption of decomposing residues. If the soil oxygen is used up, these materials will start to decompose anaerobically. Anaerobic decomposition can lead to accumulation of phytotoxic organic compounds, which are microbially converted to end-products of methane and carbon-dioxide (WATANABE, 1984*b*), accelerating the "greenhouse effect". Root injury to rice seedlings followed by stunted growth has been observed in waterlogged soils containing readily decomposable organic matter, and for subsequent crops other than rice if anaerobic conditions were not eliminated (CANNELL & 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 by excessive application of readily decomposable plant biomass has been found to increase NO_3-reduction through denitrification (PATRICK & WYATT, 1964).

In non-rice based cultivation systems, "soil-fatigue" is a well known phenomenon that can be attributed to the accumulation of potentially phytotoxic volatile fatty acids (VFAs). These compounds appear more severe and long-lasting with maturity of the incorporate in heavy, waterlogged and thus, poorly aerated soils particularly at cool temperatures (PATRICK *et al.* 1964). With *crop residues*, toxic effects of decomposing

vegetable tissues on the same or different crop species are known, e.g. lettuce (AMIN & SEQUEIRA, 1966) and Chinese cabbage (KUO *et al.* 1981). Phytotoxic substances may reach levels to kill seeds, transplanted seedlings, or even maturing plants. 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 by build-up of microbial biomass which decomposes the residue (OKEREKE & MEINTS, 1985), particularly in the early stages of the process.

Long-term application of large quantities of *green manure* was not able to hinder the depletion of soil organic matter in some rice-based environments. Soil reductive conditions were even more accelerated (WATANABE, 1984*a*). Under these conditions, decomposition of green manure can result in the formation of phytotoxic organic acids (TOUSSOUN *et al.* 1986). To avoid damage from their decomposition products, winter green manure was incorporated in China several weeks before planting rice seedlings (WEN, 1984).

1.4 Objectives

The objective of this study was to evaluate the effects of crop residues and green manure on vegetable production in tropical lowlands. Specific objectives were:

- To investigate the influence of crop residues on succeeding vegetables in year-round production
- To develop an intercropping system of vegetables with green manure as permanent live mulch
- To study the degree of interference between a regularly clipped live mulch of several legume species and vegetable crops
- To determine the short and longer-term influence of incorporated or surface-applied mulch biomass on available soil nitrogen, and on N status and yield of vegetables.

2 Materials and Methods

2.1 Management of Crop Residues and Green Manure

Residues of vegetables were cycled back to the soil for only one crop sequence in 1993/94. Crop residues were chopped into pieces and rototilled into the soil for Chinese cabbage and chili in 1993, and for carrot and vegetable soybean in 1994.

Green manure was introduced to vegetable cultivation on high beds as strips of permanent live mulch of several legume species. Vegetables were cultivated without live mulch or intercropped with live mulch at different densities (see also Fig. II-3):

1992:

- 2.00-m-wide high bed: 2 rows live mulch per 2 rows vegetable (proportion: 1:1)
- 2.75-m-wide high bed: 3 rows live mulch per 3 rows vegetable (proportion: 1:1)
- 3.50-m-wide high bed: 4 rows live mulch per 4 rows vegetable (proportion: 1:1)

1993-95:

- 2.00-m-wide high bed: 2 rows live mulch per 4 rows vegetable (proportion: 1:2)
- 3.00-m-wide high bed: 2 rows live mulch per 6 rows vegetable (proportion: 1:3)

Legume species were:

1992:

- Alyce clover (*Alysicarpus vaginalis* (L.) DC)
- Desmodium (*Desmodium intortum* (Mill.) Urb.)
- Indigofera (*Indigofera tinctoria* L.)
- soybean (*Glycine max*. (L.) Merr).

1993-95:

- Alyce clover
- Centrosema (*Centrosema pubescens* Benth.)
- Desmodium
- Siratro (*Macroptilium atropurpureum* DC.)

Live mulch was directly sown in 1992, but transplanted from a greenhouse in

1993 and 1994. When directly sown, distance between plants in rows was approximately 10 cm and when transplanted 40 cm. The live mulch was usually cut back after final harvest of vegetable crops, chopped into 10-cm pieces and either spread evenly on the soil surface as a mulch (1992 and 1993), or rototilled into the soil (1994). Additionally, live mulch was cut and applied to the soil surface during vegetable cultivation as needed. After heavy flooding caused by torrential rains in August 1994, all live mulch died and was not re-established afterwards. In 1995, one live-mulch treatment (Alyce clover) was not continued.

2.2 Study of Green Manure Application on Soil Nitrogen

To study the influence of live mulch application on soil mineralized nitrogen, chopped fresh legume material (Siratro from an adjacent area) equivalent to 60 kg N/ha (based on 20 % dry/fresh weight ratio and 3 % N/dry weight) and 60 kg N/ha applied as ammonium sulfate was rototilled into the soil on high bed plots with two replications and on three dates: 11 January, 23 March, and 13 June 1995. Plots rototilled with ammonium sulfate alone were controls. Both NH_4-N and NO_3-N were measured daily in samples taken from the 0 to 30-cm soil layer for up to 15 days. Amounts of soil nitrogen before mulching and fertilizer application were subtracted from measured concentrations.

2.3 Soil and Plant Nitrogen Analysis

Soil nitrogen and plant nitrogen were measured as nitrate content in soil, nitrate concentration in plant sap of vegetables, and total nitrogen concentration in dry matter of live mulch. Samples of soil and vegetables were taken at weekly intervals in one treatment without live mulch, and in two live mulch treatments (Centrosema and Desmodium) with two replications in 3.00-m-wide high beds (12 plots). Samples of live mulch cuttings (approximately 50 g dry weight) were analyzed for nitrogen by the Kjeldahl distillation method of material dried at 60° C for 48 h.

3 Results

3.1 Effect of Crop Residues on Vegetable Production

Incorporation of crop residues did not exert any positive effect on yield of subsequent vegetables. Non-leguminous residues (Chinese cabbage and carrot) negatively affected performance of subsequent vegetables as indicated by seedling emergence and yield. There was no effect of leguminous residues (vegetable soybean) on subsequent vegetables (Fig. E-2). Residues of chili in 1993 did not affect subsequent vegetables and no effects of incorporated residues could be detected in vegetables following the Chinese cabbage crop in 1994.

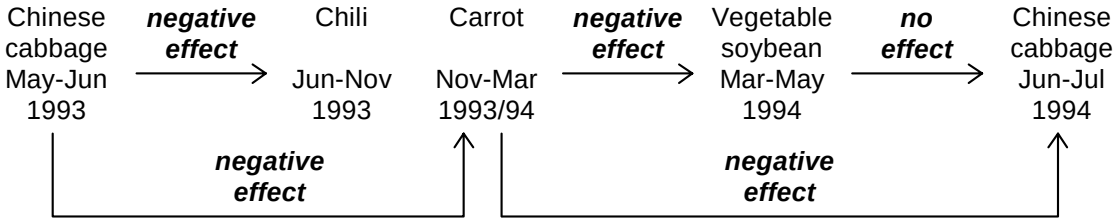

Fig. E-2 ***Effects of crop residues on vegetable production in the field experiments in 1993/94***

After incorporation of Chinese cabbage residues in 1993, yields of subsequent chili and carrot were significantly reduced by the amount of residue biomass incorporated (Fig. E-3). Biomass of carrot residues incorporated in March 1994 was negatively related to yields of the succeeding two vegetables, vegetable soybean (r^2 = 0.07*) and Chinese cabbage (r^2 = 0.28**). Under cooler temperature, the decomposing carrot residues had a detrimental effect on germination in direct-sown vegetable soybean as indicated by plant density (Fig. E-4).

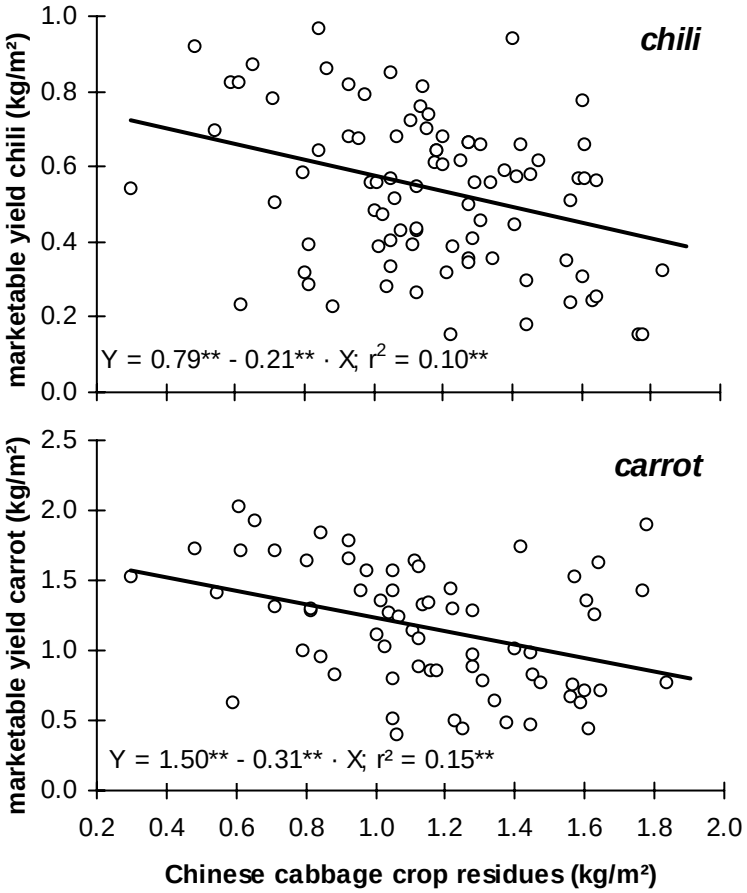

Fig. E-3 ***Effect of Chinese cabbage residues incorporated in June 1993 on yield of succeeding chili (final harvest in November 1993) and carrot (harvest in March 1994)***

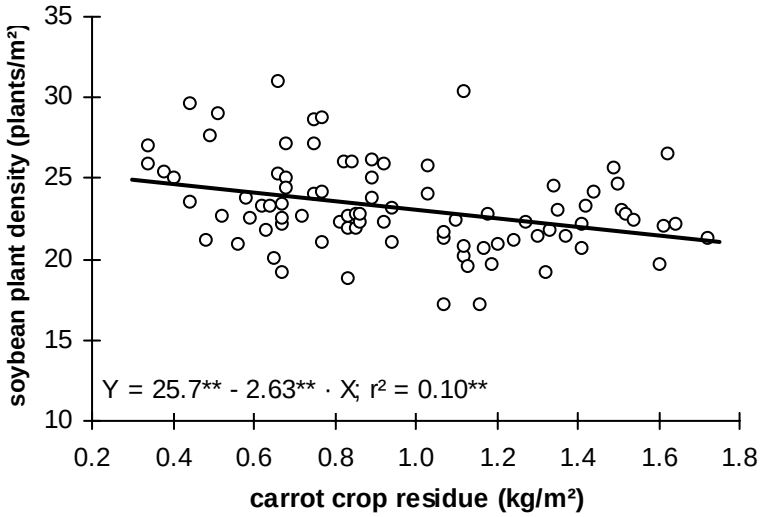

Fig. E-4 ***Effect of carrot residues incorporated in March 1994 on germination of succeeding vegetable soybean***

3.2 Effect of Live Mulch on Vegetable Production

3.2.1 Live Mulch Biomass Production

During 1992, live mulch biomass of individual legume species was not greater than in 1993 although population density was higher (Fig. E-5).

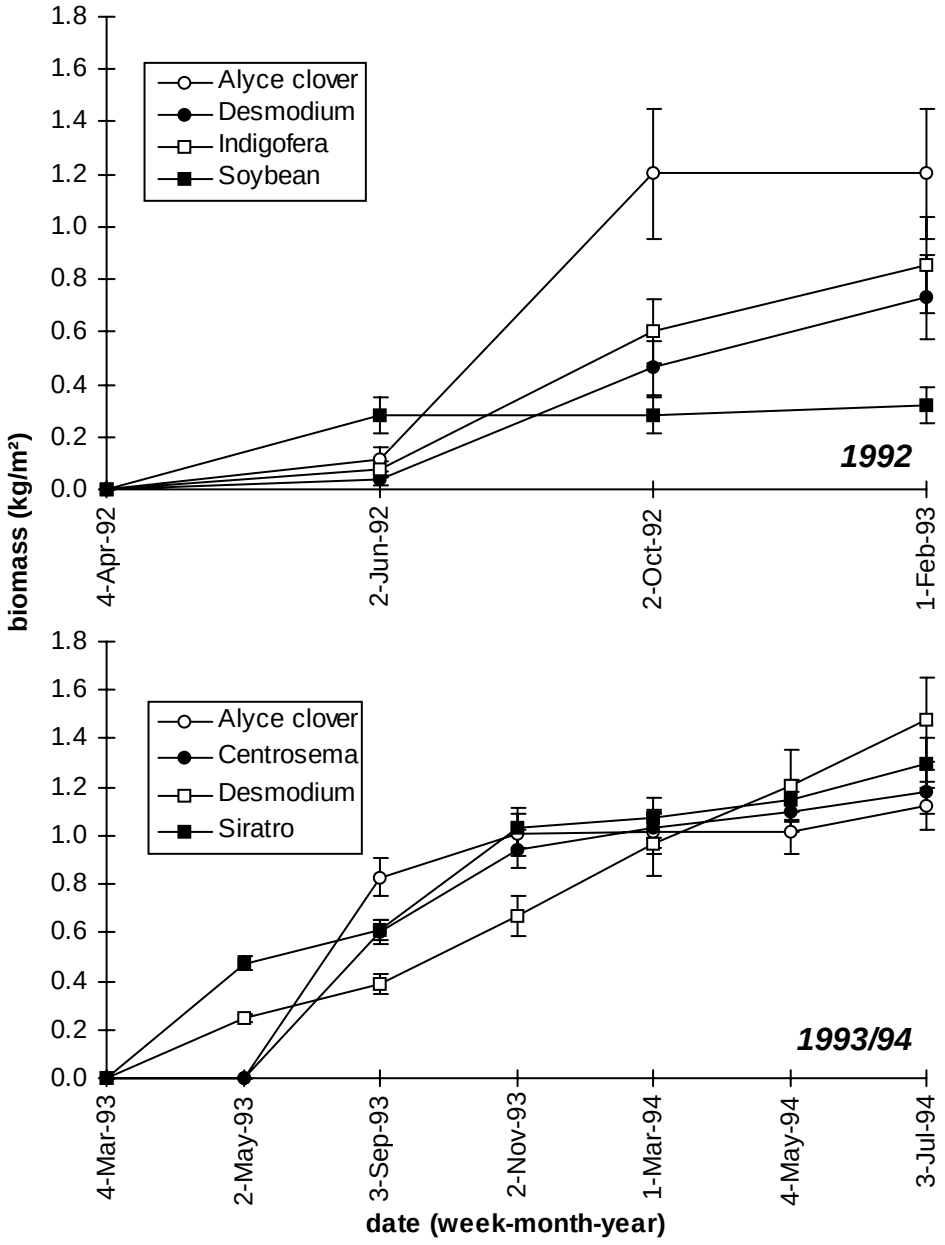

Fig. E-5 ***Cumulative live mulch biomass production of different legume species from 1992 to 1994. Vertical bars indicate standard errors***

Biomass from soybean was negligible because the annual legume had to be resown after the clipping in early June. Biomass production in 1993 exceeded biomass in 1994, but biomass was similar among species. All legume species died in August 1994. Siratro and Desmodium performed better in the warm, but dry spring (March to May 1993), but Alyce clover and Centrosema appeared to be more tolerant to hot and wet summer conditions (May to September 1993). Since all species were clipped in intervals of 2 to 4 months, only young plant material was added to the soil. The biomass characteristics (dry/fresh-weight ratio and N contents) of species were in a similar range (Table E-1).

Table E-1 ***Dry/fresh weight ratio and N content of legume live mulch clippings from 1992 to 1995*** [a]

Species	Fresh/dry weight ratio (%)	N content (% N/dry weight)
Alyce clover	25.7 ± 4.10	2.89 ± 0.11
Centrosema	19.0 ± 1.11	3.17 ± 0.32
Desmodium	20.0 ± 3.70	3.12 ± 0.03
Indigofera	24.0 ± 3.77	3.16 ± 0.07
Siratro	19.2 ± 1.05	3.11 ± 0.06
Soybean	26.1 ± 6.00	3.25 ± 0.40

[a] Mean ± standard error of two to eight determinations.

3.2.2 Competition between Live Mulch and Vegetable

The influence of live mulch on yield of vegetables can be separated into (1) direct effects during growth of live mulch (interspecific competition) and (2) residual, soil related effects after legume cuttings were applied to the soil.

The degree of direct, interspecific competition between vegetable and live mulch can be attributed to spatial arrangement and relative population density of vegetable and live mulch. When tomato was intercropped with one row of live mulch per row of vegetable in 1992 (Fig. E-6), plant biomass (yields were not determined for individual rows) was significantly reduced in all positions in beds. Competition was reduced by relocating the live mulch to the edges of high beds in 1993. Yield of chili varied greatly with position of crop row in the bed (Fig. E-6). However, live mulch (one row of live mulch located on the edge of high beds per three rows of vegetable) reduced vegetable yield only in the row close to the live mulch.

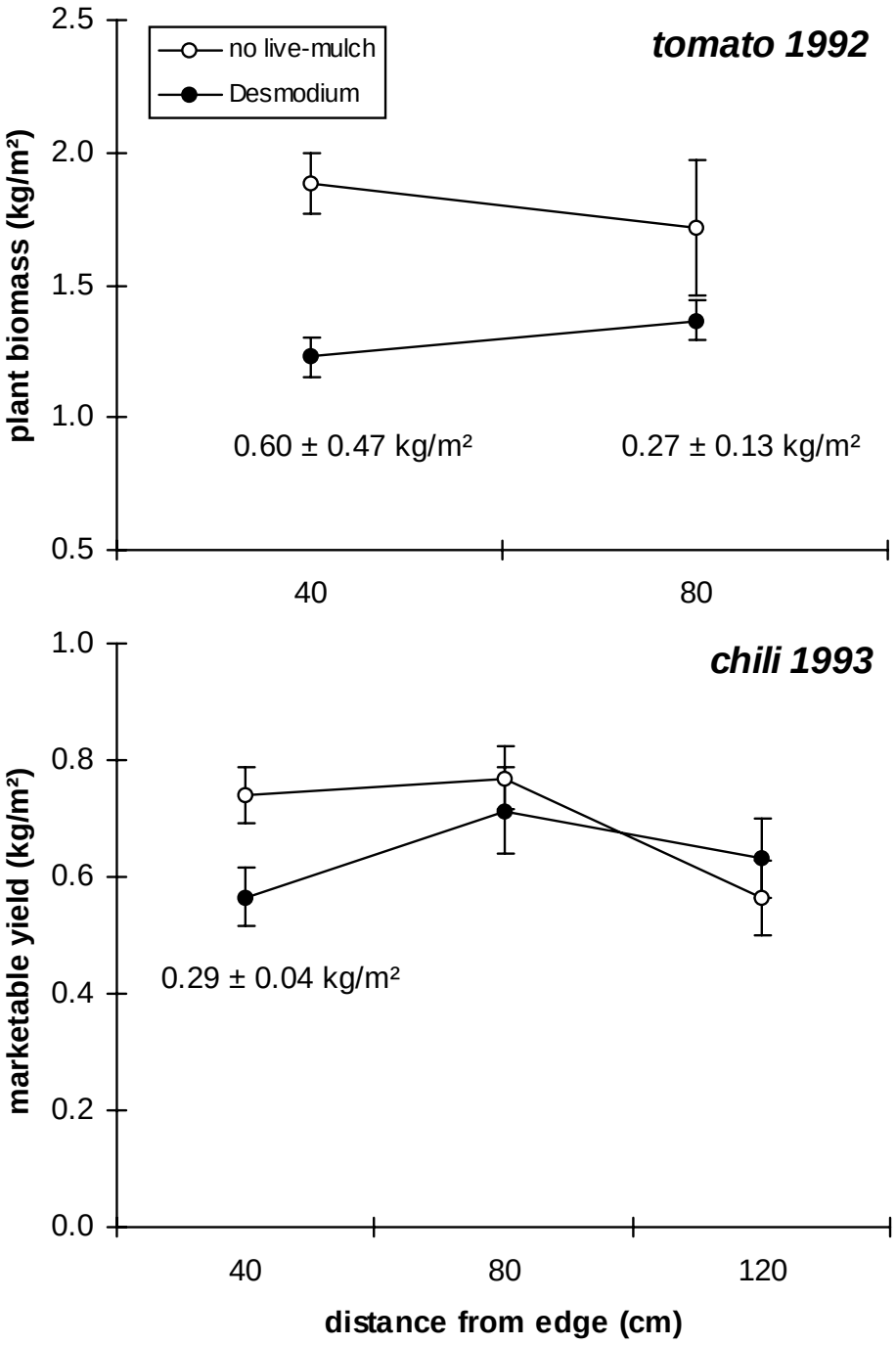

Fig. E-6 ***Interspecific competition between live mulch (Desmodium) and two vegetables in 1992/93. Values (± standard error) indicate biomass production of live mulch strips in respective positions. Vertical bars indicate standard errors***

Interspecific competition was severe in the first two years of experimentation (1992/93) as indicated by negative slopes of regressions in Table E-2. Live mulch biomass explained up to 34 % of reduction in vegetable yields (tomato in 1992). In

1994, live mulch did not reduce vegetable yield and a significantly positive relationship was found between Chinese cabbage yield and live mulch biomass.

Table E-2 ***Effect of live mulch biomass production on vegetable yield***

Vegetable and year	Regression equation [a]		
	Intercept	Slope	r^2
Chinese cabbage 1992	1.81*	-0.79*	0.23*
Tomato 1992	4.52*	-6.05*	0.34*
Chinese cabbage 1993	2.05*	0.11 n.s.	0.03 n.s.
Chili 1993	0.63*	-0.28*	0.07*
Carrot 1994	1.15*	0.12 n.s.	0.00 n.s.
Vegetable soybean 1994	1.09*	-0.10 n.s.	0.03 n.s.
Chinese cabbage 1994	1.43*	1.84*	0.13*

[a] n.s.: not significant; *: significant at $P = 0.05$

3.2.3 Residual Effect of Live Mulch on Vegetable Production

Live mulch biomass which was cut back and incorporated into the soil before sowing or planting of vegetables had no positive effect on those crops. To the contrary, yields of tomato in 1992 and Chinese cabbage in 1993 were significantly reduced by incorporated live mulch (Table E-3).

Table E-3 ***Residual effect of live mulch biomass on vegetable yield***

Vegetable and year	Regression equation [a]		
	Intercept	Slope	r^2
Tomato 1992	4.96*	-2.29*	0.20*
Chinese cabbage 1993	2.37*	-0.90*	0.33*
Chili 1993	0.60*	-0.12 n.s.	0.05 n.s.
Carrot 1994	1.14*	-0.08 n.s.	0.00 n.s.
Vegetable soybean 1994	1.07*	-0.13 n.s.	0.03 n.s.
Chinese cabbage 1994	1.60*	1.39 n.s.	0.04 n.s.
Chili 1994	0.35*	-0.02 n.s.	0.00 n.s.

[a] n.s.: not significant; *: significant at $P = 0.05$

However, the total biomass of all live mulch cuttings in 1993 was positively related to vegetable yields after May 1994 (Table E-4).

Table E-4 ***Residual effect of live mulch biomass in 1993 on vegetable yield in 1994/95***

Vegetable and year	Regression equation [a]		
	Intercept	Slope	r^2
Carrot 1994	1.24*	-0.12 n.s.	0.02 n.s.
Vegetable soybean 1994	1.10*	-0.02 n.s.	0.01 n.s.
Chinese cabbage 1994	1.31*	0.35*	0.05*
Chili 1994	0.24*	0.10*	0.16*
Carrot 1995	3.00*	0.18*	0.09*
Vegetable soybean 1995	1.16*	0.17*	0.21*

[a] n.s.: not significant; *: significant at $P = 0.05$

Incorporating live mulch cuttings had no positive short-term effect. This could be attributed to an effect of the fresh biomass on soil mineralized nitrogen which varied with season (Figure E-7).

In the *cool dry season* (January 1995), soil NO_3-N contents decreased ca. 30 kg N/ha one day after application of 1 kg/m^2 green manure (Siratro) in combination with 60 kg N/ha as ammonium sulfate. Within 14 days soil nitrate approached the level recorded for the no-mulch treatment. Obviously, there was no release of N from the decomposing legume residues. Decreases in soil ammonium did not differ between treatments.

In the *warm dry season* (March 1995), no treatment differences were obvious, indicating that no soil nitrate was immobilized in the decomposition process of legume residues, but no N was released from the legume biomass.

In the *hot rainy season* (June 1995), soil NH_4-contents decreased to zero within 6 days after combined application of fertilizer and green manure and soil NO_3 contents increased rapidly. Immobilization of soil N needed by microbes to decompose the residues was probably restricted to soil ammonium, and quick release of N from the legume live mulch was evident.

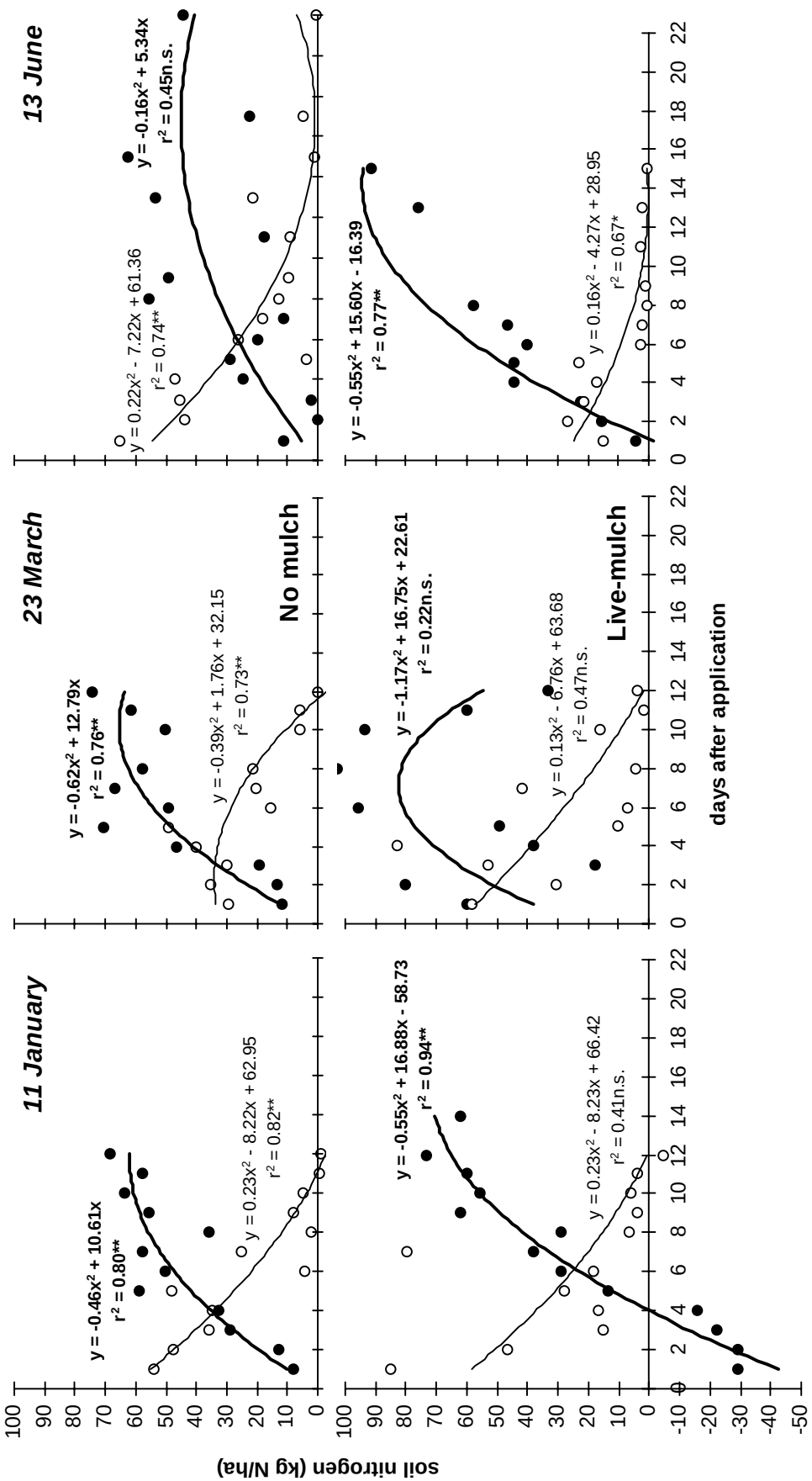

Fig. E-7 *Effect of legume live mulch on soil mineralized nitrogen. 1 kg/m² fresh live mulch (Siratro) was applied in combination with 60 kg N/ha as ammonium sulfate at three times in 1995 to high beds. Lines indicate quadratic trends for (thin line) NH_4-N and (thick line) NO_3-N*

There was a positive residual effect of legume live mulch cut back and incorporated in 1993 on vegetables in 1994/95 (Table E-4). The averages for soil nitrate and plant sap nitrate during their cultivation period were not suitable to explain this influence (Fig. E-8). Differences in plant sap nitrate reflected differences in soil nitrate, but there were no differences between live mulch and no-mulch treatments.

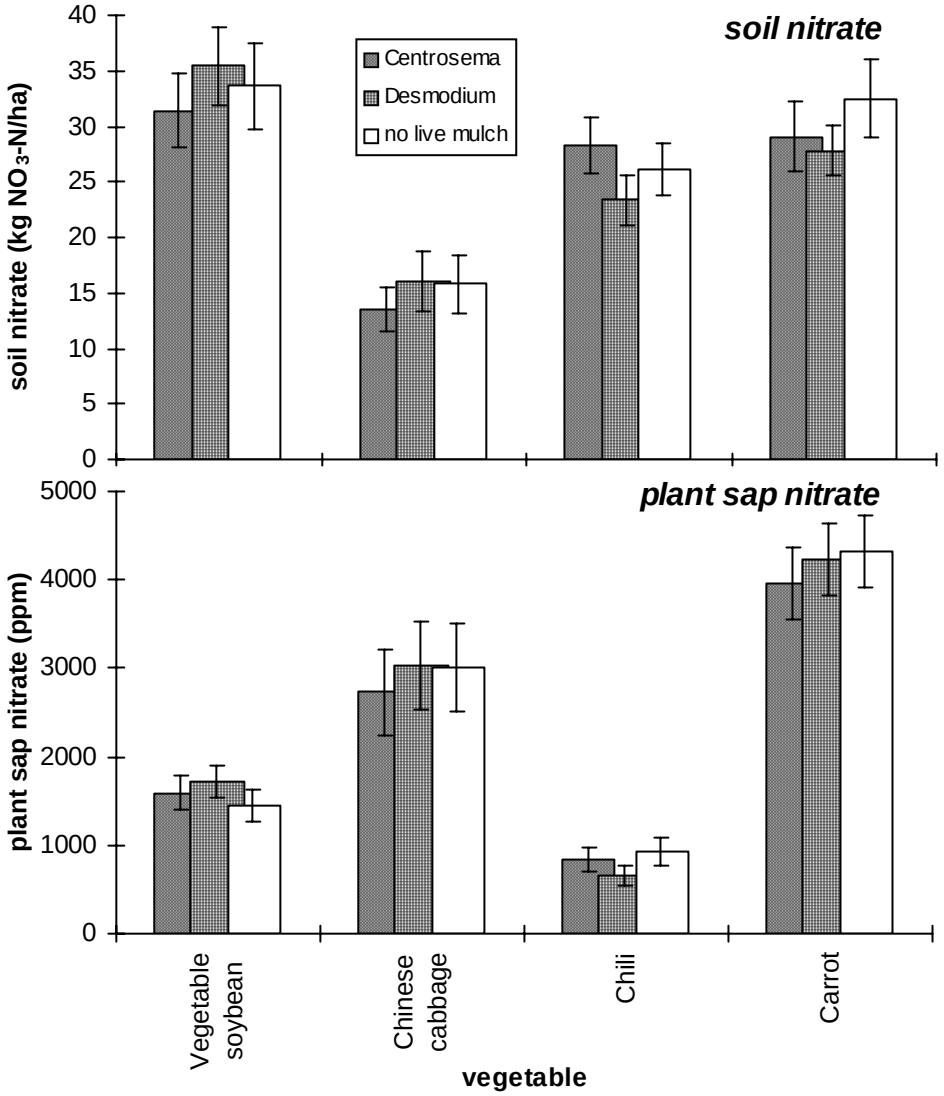

Fig. E-8 ***Effect of live mulch (two species) on soil nitrate and plant sap nitrate during the cultivation of four vegetables in 1994/95. Vertical bars indicate standard errors***

When more plots were analyzed for soil nitrate and petiole-sap NO_3 on one occasion in the cultivation period of carrot and vegetable soybean (Table E-5), no significant differences were found in soil nitrate between live mulch and no-mulch treat-

ments. However, plant sap nitrate concentrations were significantly higher in live mulch treatments as indicated by contrast *P*-values. These concentrations were, at the same time, slightly higher in the treatment in which more legume biomass (Desmodium) was produced during 1993 and 1994.

Table E-5 ***Effect of live mulch on soil nitrate and plant sap nitrate in two vegetables in 1995***

Vegetable...	Carrot		Vegetable soybean	
	Soil nitrate (kg NO_3-N/ha)	Sap nitrate (ppm)	Soil nitrate (kg NO_3-N/ha)	Sap nitrate (ppm)
Analysis of variance				
Legume live mulch				
Centrosema	59.0 a [a]	2385 a	21.2 a	469 a
Desmodium	43.4 a	2423 a	24.6 a	479 a
Mean	**51.2**	**2404**	**22.9**	**474**
no live mulch	48.7 a	2139 a	22.6 a	405 a
Contrast (*P*-value)				
mulch vs. no mulch	*0.46*	*0.04*	*0.92*	*< 0.05*

[a] Means in each column followed by the same letter are not significantly (P = 5 %) different.

3.2.4 Effect of Live Mulch on Vegetable Yield over Time

The influence of live mulch on vegetable production was a combination of competition and residual effect. On the short term, vegetable yields were reduced. On the longer term (ca. one year), vegetable yields were slightly improved, and no effect could be determined thereafter (Table E-6).

Marketable yield of Chinese cabbage in spring 1992 was not affected by live mulch since the vegetable was transplanted one month before live mulch was sown and harvested shortly after establishment of live mulch. However, no-mulch outyielded mulch treatments in crops of common cabbage and tomato in 1992, and Chinese cabbage and chili in 1993. This influence was significant when individual treatments (legume species) were compared, or when all live mulch treatments were compared to the no-mulch treatment. In 1993, Chinese cabbage yield was significantly reduced by Siratro live mulch. Total yields of chili were negatively influenced by live mulch and the comparison no-mulch versus mulch was highly significant. In 1994, yields in live mulch plots surpassed those in the no-mulch treatment. In the carrot crop in early 1995 this comparison almost reached significance. Thereafter, vegetables were not affected by treatments.

Table E-6 ***Marketable yield of vegetables on high beds as influenced by live mulch of different species from 1992 to 1995***

Year	1992		
Vegetable	Chinese cabbage	Common cabbage	Tomato
Analysis of variance (kg/m^2)			
Legume live mulch			
Alyce clover	1.53 a [a]	2.17 ab	4.86 ab
Desmodium	1.46 a	2.15 ab	4.41 bc
Indigofera	1.48 a	2.14 b	4.49 abc
Soybean	1.44 a	2.12 b	4.09 c
Mean	**1.48**	**2.15**	**4.46**
No live mulch	1.44 a	2.29 a	4.88 a
Significance level (*P*-value)	*0.93*	*0.14*	*0.01*
Orthogonal contrast (*P*-value)			
live mulch vs. no mulch	*0.69*	*0.04*	*0.06*

Year	1993			1994			1995		
Vegetable	Chinese cabbage	Chili	Carrot	Vegetable soybean	Chinese cabbage	Chili	Carrot	Vegetable soybean	Chinese cabbage
Analysis of variance (kg/m^2)									
Legume live mulch									
Alyce clover	2.14 a	0.534 b	1.04 a	1.11 a	1.41 c	0.358 a	-- [b]	-- [b]	-- [b]
Centrosema	2.18 a	0.470 b	1.24 a	1.13 a	1.66 abc	0.317 a	3.12 a	1.31 a	2.60 a
Desmodium	2.17 a	0.594 ab	1.01 a	1.02 a	1.92 a	0.354 a	3.11 a	1.30 a	2.75 a
Siratro	1.92 b	0.588 ab	1.17 a	1.04 a	1.70 ab	0.316 a	3.22 a	1.29 a	2.64 a
Mean	**2.10**	**0.547**	**1.12**	**0.82**	**1.67**	**0.336**	**3.14**	**1.30**	**2.66**
No live mulch	2.19 a	0.686 a	1.19 a	1.09 a	1.59 bc	0.294 a	2.99 a	1.28 a	2.79 a
Significance level (*P*-value)	*0.02*	*0.04*	*0.16*	*0.08*	*0.02*	*0.66*	*0.22*	*0.93*	*0.47*
Orthogonal contrast (*P*-value)									
live mulch vs. no mulch	*0.17*	*< 0.01*	*0.51*	*0.72*	*0.54*	*0.15*	*0.07*	*0.70*	*0.25*

[a] Mean separation by LSD test at $P = 0.05$; means in each column followed by the same letter are not significantly different

[b] In 1995 only three legume live-mulch treatments were continued from the previous years

4 Discussion

Crop residues are usually produced in large quantities in vegetable production. Understandably, those plant materials contain significant amounts of nutrients which should be cycled back to the soil. However, in a quick succession of vegetable crops, negative, soil-related effects of decomposing fresh residues on vegetables can probably not be eliminated. In the decomposition process, soil nitrogen and oxygen may be depleted and phytotoxic products may be produced, particularly in the anaerobic soil environment in rice-based tropical lowlands. Since detrimental effects of fresh residues are immediately apparent, e.g. by poor germination of seeds, or dying and stunted growth of seedlings, farmers frequently just depose residues which can become a problem for public health and environment. On-farm recycling of residues to make organic composts is the traditional alternative, but needs skill, time, and labor on commercial vegetable farms. Municipal composting may be successful if supported or mandated by government.

Green manure as a full crop in rotation with vegetables will likely not be successful in tropical year-round production. Farms are frequently small and the income of large families may depend entirely on producing vegetables. This makes a green-manure cycle without income unaffordable. Therefore, efforts have been made to cultivate green manure at the same time and in the same place with vegetables.

Growth and yield of vegetables grown in association with green manure are affected by factors including: inter-row spacing, timing of clipping, and placement method (KANG *et al.* 1990). SARRANTONIO (1992) discussed possible relay intercropping schemes to minimize interspecific competition, emphasizing that timing of sowing is crucial to avoid competition with the crop. When live mulch was sown into Chinese cabbage in 1992, reductions in yield were avoided presumably because the maturing vegetable inhibited legume growth. Compared to subsequent years, interspecific competition was severe in the tomato 1992 crop although only little live mulch biomass (0.03 to 0.07 kg/m^2) was produced. This could be attributed to differences in proportion and spatial arrangement of live mulch and vegetable (RADOSEVICH & WAGNER, 1986). In 1992, the proportion of live mulch to vegetable was 1:1 row, and subsequently only 1:3 rows. Arrangement of live mulch on the edges of beds limited competition to the border row of vegetables (Fig. E-6). Growing

the live mulch strip in between vegetable rows would have probably resulted in more severe competition between live mulch and vegetable after 1992.

Incorporation of legumes before vegetables were established did not improve performance of crops (Table E-3). Although it is often anticipated that a short-term nitrogen flush after incorporation may favor the yield of a succeeding cash crop, nutrients in the green manure biomass may not mineralize in time to become available to the following crop. Green manure may even immobilize soil nutrients that were available before application (YAMOAH & MAYFIELD, 1990) through the buildup of soil microbes stimulated by the application of decomposable plant material. This process has been observed with green manure and legume crop residues in some rice-based environments (AVRDC, 1992; AVRDC, 1995). This shows that temporary immobilization can be significant even when high-nitrogen-containing material is added to soil (STOJANOVIC & BROADBENT, 1956). The effect is obviously determined by temperature: incorporation in the cool season resulted in initial immobilization of soil nitrate and virtually no release (Figure E-7). Similar negative effects of green manure application were observed by PATRICK *et al.* (1964) in poorly aerated rice soils and particularly when temperatures were cool. In the hot season release of nitrate was more pronounced.

The influence of live mulch application was only evaluated with additional fertilizer application. WILSON *et al.* (1986) showed that nitrogen deficiencies developed in crops after legume application when extra nitrogen was not applied. Poorer vegetable crop performance after legume incorporation was, however, also observed when fertilizer was added (AVRDC, 1992).

Live mulch biomass in vegetable production was usually negatively correlated with crop yields in the short term (NICHOLSON & WIEN, 1983; WILES *et al.* 1989), and MULONGOY & AKOBUNDU (1992) stated that competition between live mulch and vegetable is more severe in newly established live mulch plots. Therefore, no benefit can be expected when the establishing live mulch reduces growth and yield of associated crops. Slow but steady improvement in crop yield has, however, been recorded by BALASUBRAMANIAN & SEKAYANGE (1991) after the first year of establishing a legume hedgerow system. WARMAN (1990) attributed a positive yield response in tomato to residual fertility of a previous year's live mulch system with cauliflower, and MULONGOY & AKOBUNDU (1992) found sustained maize yield after a lag of two years

from the time of live mulch establishment. These results can be partly confirmed for vegetable production in tropical lowlands. Soon after establishment of live mulch in 1992 and 1993, vegetable yields were inhibited, but biomass of live mulch cuttings in 1993 improved vegetable yields in the following year (Table E-4). The findings that positive effects of a legume cover crop may not last for more than a year after incorporation (UTOMO *et al.* 1992) were confirmed since live mulch significantly improved vegetable yields for only a few crops (Table E-6).

Positive longer-term effects of green manure or cover crops were often associated with improvements in soil chemical and physical properties (LAL *et al.* 1978). In intensive vegetable cultivation, GYSI & KELLER (1983) found that loss of organic matter was significantly inhibited by a green manure intercrop. Effects of live mulch on available soil nitrogen could not be detected, but there was an indication that plant nutritional status was improved in live mulch treatments (Table E-5). This might have been resulted from slow, but sustained mineralization of organic nitrogen which was improved by the live mulch biomass application in previous years. This nitrogen was obviously readily absorbed by vegetable crops.

The practical significance of a live mulch system in intensive tropical vegetable production appears, however, minimal. Management of such a system is too expensive and labor-intensive (KELLY, 1990), negative effects may be obvious on the short term, and positive longer-term effects, if any, may not be recognized by farmers. The only viable alternative may be composting of organic matter such as harvest residues. Well matured composts could be periodically returned to the fields for long-term improvement of soil structure. But again, economical constraints may overrule ecological benefits.

IV Economy of Crop Management Technologies

1 Introduction

Diversification of traditional land use forms for production of high value crops to increase farmer's income has been extensively promoted in Asia (HSIEH & LIU, 1986). In the more developed parts of Asia, increase in per-capita income is changing the traditional eating habits: total calorie intake from grains is substituted by vegetables, fruits, and animal products (VON UEXKÜLL, 1995). In these and in less developed countries, farmers are increasingly confronted with narrowing margins of profitability for traditional crops (PINGALI, 1992). Vegetables are an important commodity in the diversification of crop production. However, only few studies (e.g. JANSEN *et al.* 1996*a*; JANSEN *et al.* 1996*b*) have evaluated the income-generating capacity of vegetables as an alternative to traditional field crops such as rice.

Vegetable production in the tropics frequently corresponds with (1) large seasonal variations in supply, price, and consumption, and (2) over-use of agrochemicals and fertilizers. The seasonality in vegetable production and consumption in the tropics stems to a large extent from unsuitable production conditions in the tropical lowlands during the rainy season in which supply does not match demand, and prices are high. This has significant implications for the nutrition of poorer sectors of the community, which spend a large part of expenditures for food (SMIT, 1995). Crop management technologies have the potential to tackle production constraints during the rainy season to facilitate stability of vegetable supply and price. At the same time, they may also be suitable to reduce agrochemicals and fertilizers in tropical vegetable production. However, only few analyses are available which evaluate the economic viability of such improved crop and field management techniques (e.g. MIDMORE *et al.* 1997).

Decision-making of farmers is extremely complex and cannot completely be simulated by mathematical procedures (PANNEL, 1995). However, capital-budgeting approaches (EHUI *et al.* 1990) may be useful for determination of profitability of vegetables compared to traditional production of field crops, and for determination of economic feasibility of field/crop management technologies.

At the farm-level, vegetable production can be initiated at small scale with little

investment and skills. Low productivity can be improved by advanced land-use systems and management technologies which may raise significant investment costs. In those more efficient micro-enterprises, availability of labor and degree of mechanization largely determine production costs. Additional returns from improved management techniques may not appear immediately and may not even be recognized by farmers. Investment in technologies for environmental protection and resource-efficient production may not be profitable for a farmer, but improve health and "quality of live" for the whole community. In economies which depend substantially on their farming industry, governmental forces play an important role in promoting and regulating crop production systems.

The objective of this study was to determine the profitability of vegetable production and crop management technologies in tropical lowlands. Specific objectives were:

- To compare the profitability of vegetable production versus rice production in a representative farm
- To determine the influence of crop management technologies on the longer-term profits of a vegetable farm
- To rank management techniques according to their effect on farm profits

Scenarios of different combinations of management techniques were studied considering different levels of labor availability, labor input, and farm capital.

2 Procedure and Data

It is assumed that all cropping systems are practiced with "best technical means" (DE KONING *et al.* 1995), i.e. availability of labor, farm equipment and capital, and marketing of the agricultural produce present no limitations under respective production scenarios. Maximizing profits in a planning horizon of three years is the assumed objective of a farmer. This is a typical time-frame for rotating vegetables with rice in southern China (CHANDLER, 1981) and Taiwan (SU, 1981). The average size of a self-

owned, sole-rice farm was estimated at one hectare (Hopi county, Tainan prefecture; ROAN, personal communication). Farmers grow two crops of rice during one year, one spring crop and one summer crop. The rice harvest is sold to local farmer's associations at an official, subsidized price.

It is simulated that a farmer substitutes some part of his rice-land (in increments of 500 m^2) to vegetables. For cultivating these vegetables, the farmer adopts the management techniques of (1) permanent high beds, and (2) the "N_{min}-reduced" method. Technologies of "integrated analysis of soil and plant nitrogen" and "green-manure and crop-residue management" were excluded since no significantly positive effects on increasing vegetable production, saving external inputs, and protecting the environment were found. Vegetables are sold at a free-market price on the base of monthly average prices at Taipei whole sale market (TFVTSC, 1993-95). Average production costs of crops (Table IV-1) were derived from the Taiwan Agricultural Yearbook 1994 (DAF, 1995). These costs were based on (3) different levels of labor availability (family labor, hired labor), (4) labor input (manual labor, mechanization), and (5) availability of capital (from own savings, credits; Table IV-2). Costs were assumed to arise evenly during the cultivation period of crops and not at specific dates (e.g. time of sowing, weeding, harvest).

(1) Construction costs for *permanent high beds* were derived from own field experiments and from interviews with farmers in Changhua county (central Taiwan), where construction of such beds is fully mechanized (Table IV-3). Construction costs for flat beds which were prepared before onset of each vegetable crop were not considered, neither were differences in other production costs between flat and high beds (e.g. irrigation).

(2) Fertilizer costs in 1993 were 4.60 NT$/kg for ammonium sulfate, 3.40 NT$/kg for calcium superphosphate, and 4.80 NT$/kg for potassium chloride (1.00 US$ ≈ 1.50 DM ≈ 25 NT$). Costs for the *$N_{min}$-reduced method* (labor and equipment for carrying out analyses and calculations) were neglected.

Table IV-1 ***Estimated costs (NT$/ha), labor input (man-hours), and cultivation period of aquatic and vegetable crop production in Taiwan, 1992/93***

Costs and labor	Aquatic crops			Vegetable crops			
	Japonica rice	Indica rice	Taro	Chinese cabbage	Chili	Carrot	Vegetable soybean
Direct costs							
Seed & Seedling	5961	4187	9180	2498	21372	2305	17118
Fertilizer	3815	4473	7841	3805	7599	5531	2923
Labor	25088	27668	76403	104824	123761	32999	37259
Animal labor & mechanization	31515	25130	54309	3494	10141	2877	1484
Chemicals	4963	4487	7685	8576	20221	10247	6427
Energy	0	0	0	262	331	349	595
Materials	432	189	0	0	17747	0	0
Total	71774	66134	155418	123459	201172	54308	65806
Indirect costs							
Irrigation	637 [a]	5267 [b]	1320	0	0	0	0
Buildings	226	118	351	393	389	393	408
Farming tools	280	148	424	449	477	449	523
Total	1143	5533	2095	842	866	842	931
Total costs	72917	71667	157513	124301	202038	55150	66737
Labor (Man-hours)	170	170	347	1081	1522	447	1124
Cultivation period (weeks)	16	19	33	6	18	15	10

[a] partly irrigated during the rainy season; [b] fully irrigated during the dry season
Source: DAF (1995)

Table IV-2 ***Change in estimated total costs for aquatic and vegetable crop production by switching to alternative production systems***

Production system… Alternative system…	Manual labor Mechanization (NT$/ha)	family labor hired labor (NT$/ha)	standard fertilization N_{min}-reduced rate ∅ (NT$/ha)
Aquatic crops			
Japonica rice	--	--	--
Indica rice	--	--	--
Taro	--	28236	--
Vegetable crops			
Chinese cabbage	-4396	8528	-1535
Chili	--	30103	-1095
Carrot	--	6943	-2082
Vegetable soybean	-8052	48457	-1090

Source: DAF (1995) and own calculations

Table IV-3 ***Construction costs (NT$/ha) of permanent high beds as affected by mechanization in Taiwan, 1992/93***

	Manual labor [a]	Mechanization
Construction	451400 [b]	16000
Reconstruction	238300 [c]	16000

[a] hired labor, salary 1254 NT$/work-day
[b] 360 work-days/ha; [c] 190 work-days/ha
Source: interviews and own calculations

(3) *Labor* costs of family labor were included as opportunity costs to account for possible income generation of idle family labor in industry or business (DAF, 1995). Since labor costs were calculated on a per-unit-area basis, differences in labor requirement (e.g. for harvest) due to greater crop productivity were not considered.

(4) Production costs were separated according to the *labor input*, i.e. the degree of farm machinery available (DAF, 1995).

(5) It was assumed that (a) a farmer would cover costs of investment and production from his own savings, or (b) all negative balances would be covered by *credits* from the local farmer's association for short-run financial survival. Annual interest rate in 1995 was 10.75 % for a 1-year credit and 11.50 % for a 2 to 3-year credit. It is assumed that a farmer decides to take a credit at the beginning of each year, the sum borrowed covers all negative balances in the succeeding year, a farmer has a preference for slightly more costly longer-term credits rather than cheaper short-term credits

with higher monthly repayment rates, and debts are paid back by constant monthly rates each year.

By combining the two levels of each: (1) adoption of permanent high beds, (2) adoption of the N_{min}-reduced method, (3) labor availability, (4) labor input, and (5) the requirement for credits, 32 production systems for vegetables were distinguished.

3 Results

3.1 Production Costs

There were significant differences in production costs between aquatic crops and upland vegetables, however, for both crop types fertilizer costs comprised only a fraction of the costs for labor and mechanization (Table IV-1). Costs for animals and mechanization were much greater in rice and water-taro compared to vegetables. This can be attributed to preparing planting beds by wet plowing ("puddling"). Irrigation of vegetables was included in direct costs. There were no alternative production systems for rice since seedlings are usually raised and machine-transplanted by farmer's cooperatives (Table IV-2). In contrast, water-taro is invariably transplanted by hand. Labor requirements, and therefore labor costs, were greater for vegetables, particularly for the transplanted species Chinese cabbage and chili. Labor costs *per man-hour* ranged from 148 to 220 NT$ for aquatic crops, but only 33 to 97 NT$ for vegetables. This is due to better salaries for work in flooded fields. However, labor input *per unit time* was usually greater for vegetables since crop cycles were shorter. This was particularly true for Chinese cabbage. Although cultivation of vegetable soybean required high labor input, direct labor costs were not so great and could be significantly reduced by mechanization (Tables IV-1 and IV-2). This is due to the fact that vegetable soybean harvest is usually done by older workers or pensioners by hand-picking of pods. Lower salaries then compensate for the high requirement of hand work which may continue throughout the nights during the harvest period.

Table IV-3 illustrates the immense costs for highly paid labor, and thus capital, to construct permanent high beds without mechanization. Mechanization can save those

construction costs substantially. However, the vegetable cultivation area in Changhua county, which is Taiwan's largest vegetable production region and where permanent high beds are the preferred cultivation system, show that such mechanization requires expensive, powerful, and often specially constructed equipment. Such equipment may not be available to farmers and individuals cannot usually afford it. Therefore, in Taiwan, this is purchased by and used in a farmer's community.

3.2 Market Supply and Prices

The guaranteed price for Japonica and Indica rice from 1993 to 1995 was 19 NT$/kg and 20 NT$/kg. Market supply and price of vegetables varied with season (Fig. IV-1). Supply of *Chinese cabbage* to Taipei wholesale market was much greater than for all other vegetables studied, outlining the importance of this crop. Supply peaked during dry season, and was low during the rainy season. When Chinese cabbage was in short supply, market prices increased manifold, but for only a limited period of two or three months. Although seasons were not so clearly reflected in market supply of *chili*, higher prices prevailed longer. This variation of supply and price can be primarily attributed to the intolerance of Chinese cabbage and chili to flooded soil conditions. These were particularly pronounced in 1994 after torrential rains of more than 1,300 mm in the first two weeks of August. Seasonality in supply of *carrot*, was not pronounced. This can be attributed to the good storage capability of carrots. Prices were somewhat higher during the rainy season, perhaps exacerbated by the restricted supply of all vegetables. Market price of *vegetable soybean* was high during the dry season when supply was low. This seasonality corresponds primarily with low temperatures to which vegetable soybean is not well adapted.

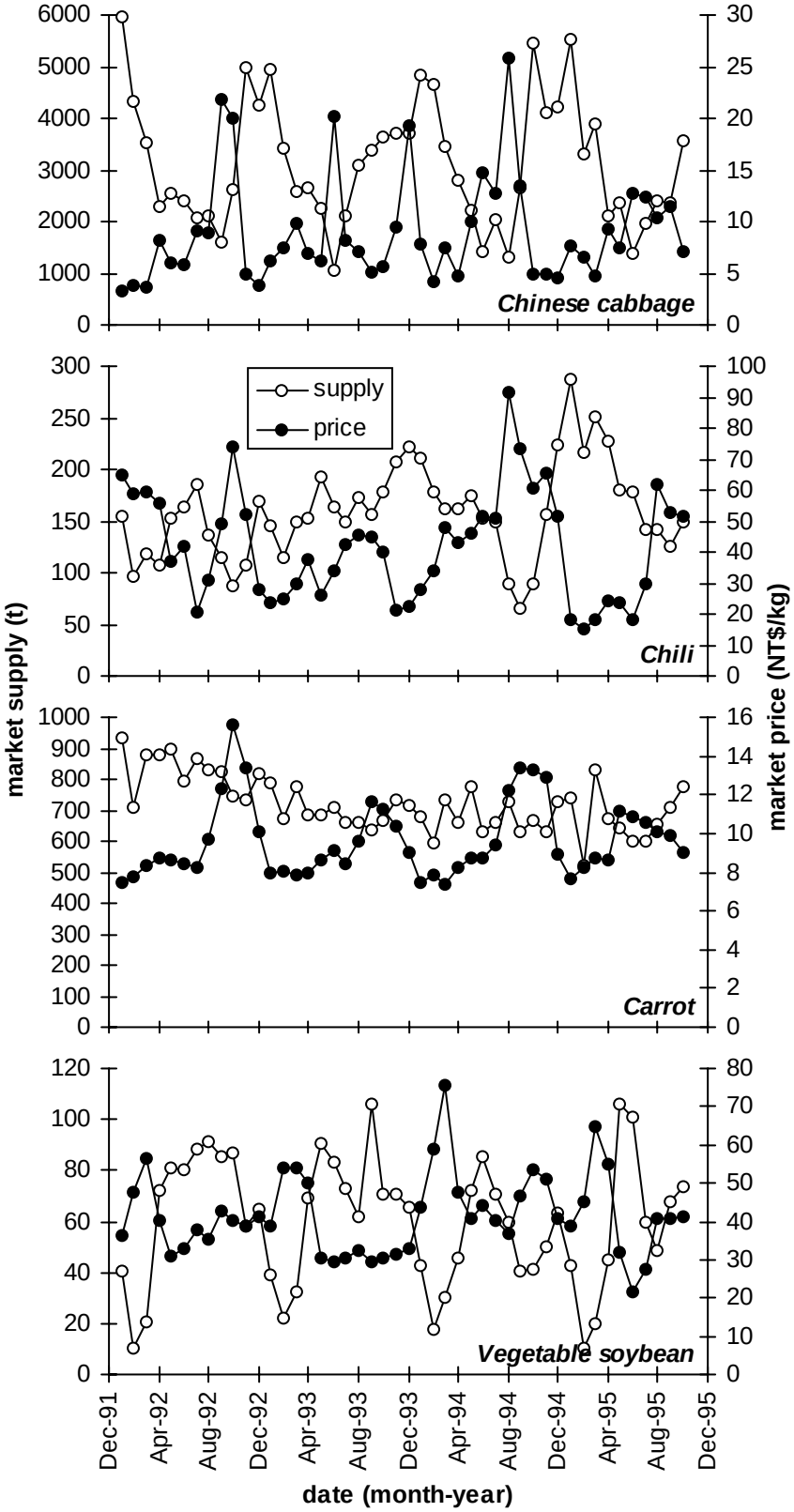

Fig. IV-1 ***Supply and price of four vegetables at the Taipei wholesale market from 1992 to 1995***

3.3 Profits

The influence of crop management technologies on vegetable yield is presented in Chapters A to E. Yields of *aquatic crops* were more affected by season than by cultivation systems (Table IV-4). Yields of the second rice crop in the rainy season remained behind yields of the first crop in the dry season. This was due to adverse weather conditions and damage by birds. Yields of water-taro remained low considering the long growth period.

Table IV-4 ***Yields of aquatic crops in the high bed system and flat bed system from 1992 to 1995***

Aquatic crop	High bed system (kg/m^2)	Flat bed system (kg/m^2)
Japonica rice dry season 1992	0.55	0.59
Indica rice rainy season 1992	0.17	0.19
Japonica rice dry season 1993	0.72	0.79
Indica rice rainy season 1993	0.10	0.30
Water-taro 1993/94	0.53	0.52
Indica rice rainy season 1994	0.38	0.20
Japonica rice dry season 1995	0.68	0.62

The three-year simulation of costs and returns of a one-hectare rice farm with 1,000 m^2 allocated to vegetable cultivation (not shown) indicated that costs of vegetable production per unit area were on average more than twice as high as for rice (Table IV-5). However, net returns per unit area from vegetables outstripped returns from rice by ca. three times. Therefore, one square meter of vegetables could substitute three square meters of rice in terms of net returns. The return-to-cost ratio of vegetable production was much higher for vegetables than for rice.

Table IV-5 ***Economy of rice and vegetable production in the field experiments from 1992 to 1995***

	Rice production	Vegetable production
Costs per unit area	45 NT$/$m^2$	102 NT$/$m^2$
Net returns per unit area	54 NT$/$m^2$	153 NT$/$m^2$
Return-to-cost ratio	1.2	2.5

Net returns from rice cultivation over the years 1993 to 1995 ranged from -3.2 (± 2.0) NT$/$m^2$ to 7.1 (± 0.7) NT$/$m^2$. The rice crops during the dry season were always

profitable whereas the crops during the rainy season generated negative income when adverse weather conditions prevailed during the cultivation period (rainy seasons in 1993 and 1994). The introduction of water-taro as a substitute for rice did not improve net returns for the aquatic component on a per-area basis (-0.2 ± 1.6 NT$/m^2), nor on a per-unit-time basis.

Chinese cabbage in the rainy season and vegetable soybean in the dry season were the most profitable crops (Fig. IV-2). High-bed technology significantly improved yields of Chinese cabbage and chili in the rainy season. However, monetary returns from off-season Chinese cabbage differed from year to year because of large price fluctuations. Better yields of chili on high beds during the rainy season did not generate much income compared to Chinese cabbage, particularly in view of the long cultivation period. Without considering high-bed construction costs and credit interest, net returns from vegetables were always in the range of profitability with high beds, but not so with flat beds. Chili in 1993, and both summer crops of Chinese cabbage and chili in 1994, generated negative income when cultivated on flat beds.

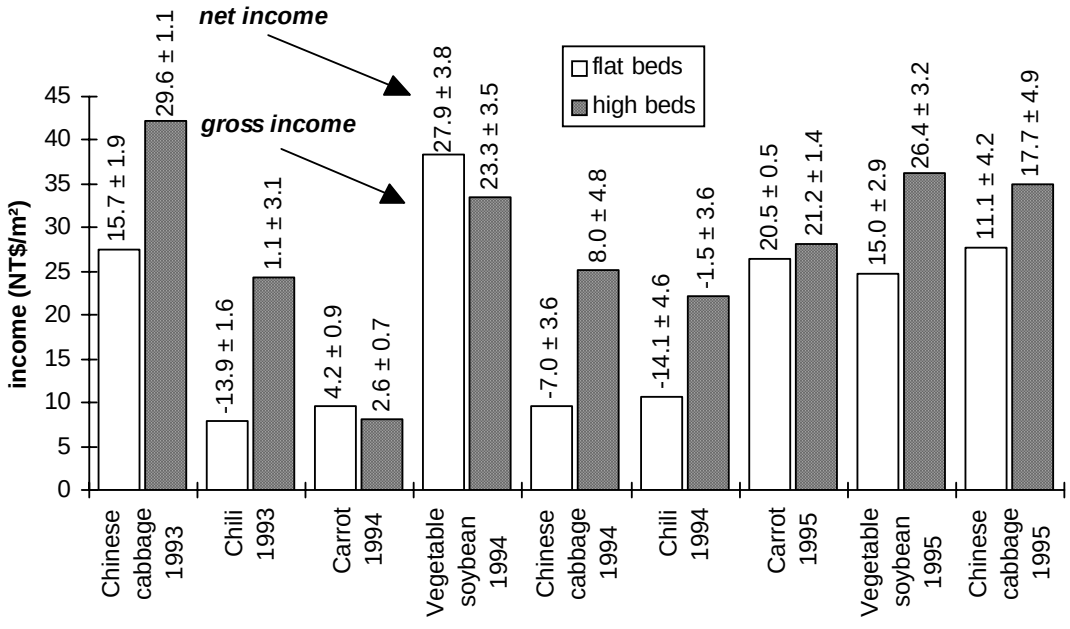

Fig. IV-2 ***Influence of cultivation system on gross returns (bars) and net returns (values ± range) from vegetable production 1993 to 1995***

Figure IV-3 shows the development of farm capital for the simulated one-hectare farm under three scenarios: (1) sole rice, (2) including 1,000 m^2 vegetables on flat or (3) on high beds. Capital costs were too high for the sole-rice farm to be profitable at

the end of the three-year period presupposing liquidity of the household. Introduction of vegetables ensured both liquidity and profitability of the farm. High bed cultivation of vegetables was superior to flat bed cultivation and the difference in profitability increased with time, indicated by the widening gap between both curves in Fig. IV-3.

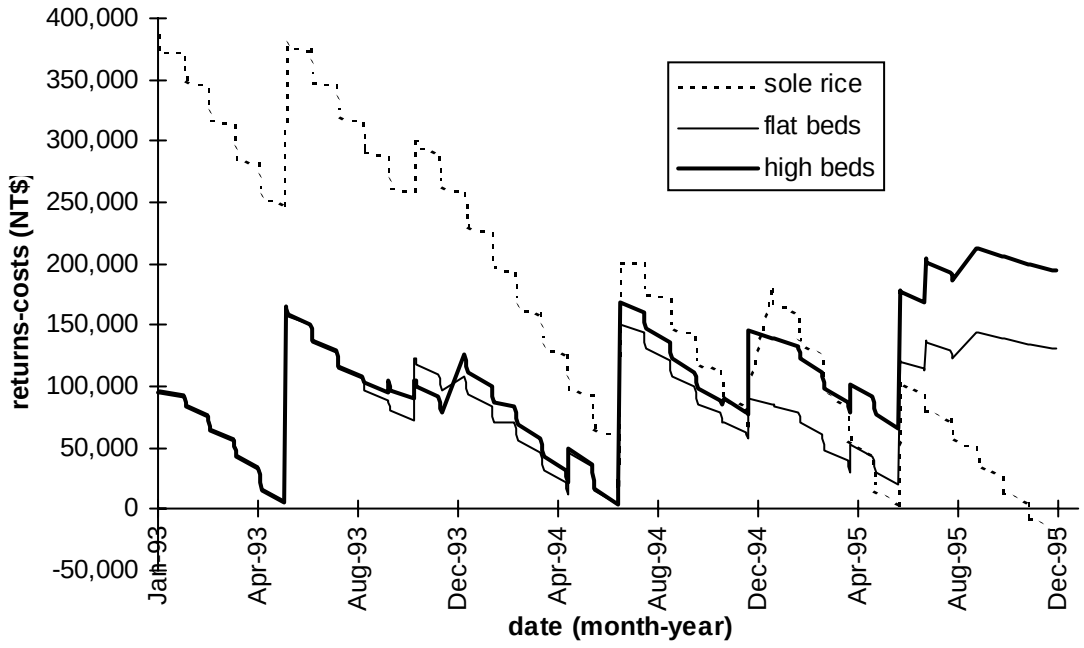

Fig. IV-3 ***Simulation of development of farm capital (returns - costs) as influenced by three scenarios: (1) one-hectare sole-rice farm, 1,000 m^2 allocated to vegetable production on (2) flat beds and (3) high beds (family labor, mechanization, incl. credit costs, traditional fertilization)***

3.4 Ranking of Management Technologies according to their Profitability

On average (with and without credit costs), the one-hectare sole-rice farm generated 72,767 NT$ income over three years (Fig. IV-4). By adopting 1,000 m^2 vegetables this net return increased by 83,336 NT$. The total net incomes in Fig. IV-4 must be viewed in the context of an annual on-farm income of 182,953 NT$ in Taiwan in 1992 (DAF, 1995). Compared to this average of all agricultural farms in Taiwan, the calculated incomes in Fig. IV-4 underestimate the income-generating capacity of farms. The most decisive factor for profitability of vegetable production was the availability of *family labor*. With family labor, net returns were 47,902 NT$ greater than with hired labor. The second most important factor governing profitability of

vegetable production was the availability of machinery (*mechanization*) to reduce labor-input, particularly when labor was hired and, therefore, costly. The decision to adopt *high bed technology* was more important when family labor and machinery were available. In this case, high beds improved net returns by 63,868 NT$ compared to standard flat beds irrespective of construction costs. Availability of *capital* was not much important. When labor had to be hired and labor-saving machinery was not available, the influence of capital costs on total net returns was more decisive than the decision whether to adopt high bed technology or to rely on traditional flat beds. In all scenarios, saving of fertilizer costs by the N_{min}-*reduced method* could not match the reductions in yield and monetary returns. This factor was, however, of least importance for the profitability of the simulated farm. The greatest income was generated with high bed technology when family labor and machinery were available, and when production costs could be covered by own capital (366,167 and 312,511 NT$). With the same set of production factors, vegetable production on traditional flat beds generated only 222,788 and 187,083 NT$ net income, about 65 % less than production on high beds. When no family labor and no machinery were available, and costs had to be covered by bank loans, high beds were in the least profitable set of production factors (94,324 and 31,221 NT$). This is, however, a rather unrealistic scenario in vegetable production.

4 Discussion

The cost-benefit analysis of a sole-rice farm confirmed the low profitability in rice production despite governmental subsidies for production factors and protection of domestic prices (PINGALI, 1992). This is true for both better and less developed countries. Field studies for less developed countries than Taiwan (Nepal, JANSEN *et al.* 1996*a*; Vietnam, JANSEN *et al.* 1996*b*) have highlighted that annual returns were greatest in vegetable farms. This is confirmed since vegetable production was estimated to be five times more profitable than rice (net returns: 51 NT$/m^2 and 9 NT$/m^2). Diversification of rice to an alternative field crop, water-taro, did not improve profitability or farm income due to low yields. Economically successful cultivation of this crop will likely hinge on desirable experience and skills of specialized farmers (LIOU, 1979). Therefore, to improve farmer's income, complementation of

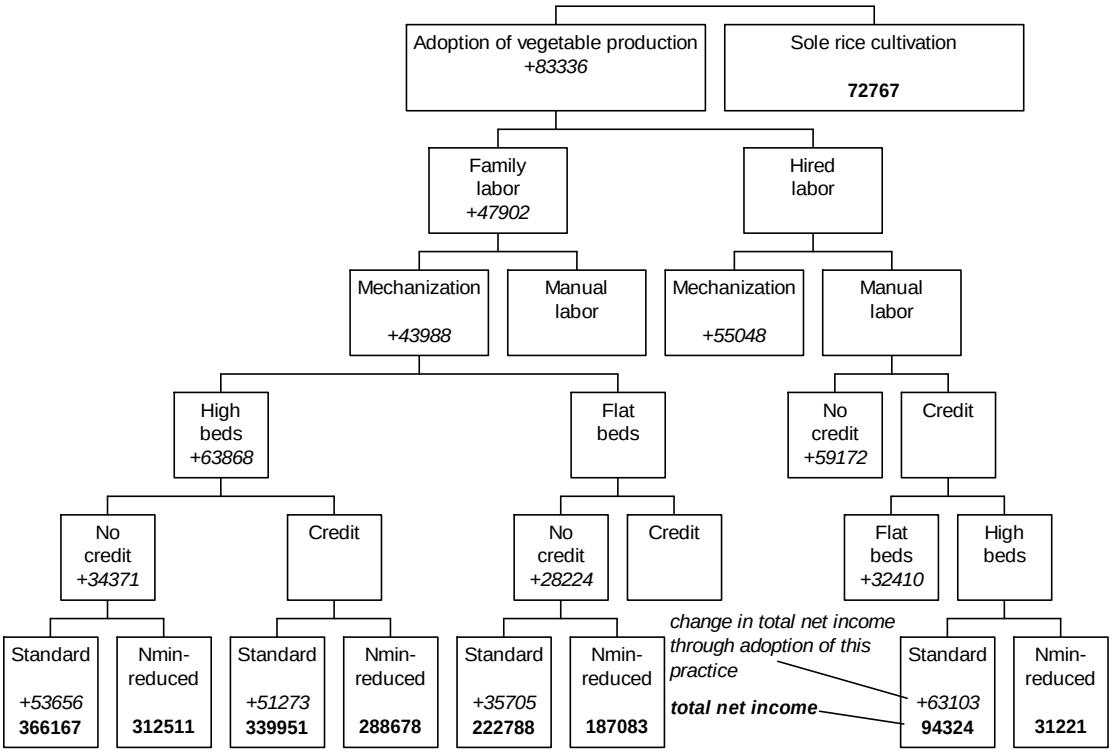

Fig. IV-4 ***Ranking of factors according to their effect on profits (NT$) of a simulated one-hectare rice farm with or without allocation of 1,000 m^2 to vegetable production***

field crops with high-value crops such as vegetables is of great importance in tropical agriculture. Vegetable production can be initiated at small scale with little experience and skill, close or distant to markets. With rising intensification, closeness to cities as the markets for supply of production factors and demand for the vegetable produce is more desireful, and make peri-urban regions more suitable for vegetable production. Since costs for land are usually high in those regions, rice production will be even more uneconomical. Increasing production of vegetables may affect prices and the income of farmers, but increases affordability for the community.

Vegetable market prices tend to differ greatly by season in a given year, and between the same seasons in different years. This was particularly true for Chinese cabbage.

The relative importance of production factors for overall profitability of vegetable cultivation was ranked in the order: (1) availability of family labor, (2) labor input, (3) cultivation system, (4) credit costs, and (5) fertilizer consumption.

(1) Greatest profitability of vegetable production on a per-unit-area basis was achieved when family *labor* was utilized. Consequently, vegetable production area could preferably be enlarged to the extent that family labor can manage its cultivation. Profitability sharply decreased when labor had to be hired. Two main difficulties arise with hired labor in tropical vegetable production: scarcity and increasing salaries. Farmers often restrain from expanding their vegetable cultivation because of insufficient availability of labor. In Taiwan, average daily salary for man labor increased from 486 NT$/day in 1984 to 1,254 NT$/day in 1993, a yearly 18-percent increase. In other countries, availability of labor and labor-costs may develop in a different direction: particularly around the sprawling cities, unemployment is rising. Vegetable farming can create jobs in those regions. When farmers concentrate on rice production, vegetable production can be helpful in alleviating idle time of available workers. However, timing of crops can be difficult. In the fallow period of rice during the dry season, labor is idle, but vegetables fetch low prices. In the rainy season, vegetable prices are high, but labor is employed in rice cultivation.

(2) Understandably, saving of *labor-input* by mechanization of farm operations was of much greater influence on profitability when labor was hired. Also, in view of widely prevailing labor shortages even simple labor-saving practices are of great importance in tropical vegetable production.

(3) The appropriate choice of the *cultivation system* depended on availability of family labor and machinery. It was more advantageous to choose traditional flat beds when labor was hired and no machinery was available, whereas permanent high beds had to be adopted to achieve greatest farm benefits. This highlights that introduction of a specific crop-management technique should be accompanied by other measures to ensure success. Construction costs for high beds (68,970 NT$/1,000 m^2) were similar to the credit costs (interest) for a whole one-hectare farm (61,806 NT$), and only a fraction (11 %) of total production cost. Since vegetable production is generally cost-intensive, the costs for high bed construction and other advanced management techniques are not excessive when related to the other costs of production. Taiwan's vegetable production zone in Changhua county is a good example how such investment costs can be reduced by farmer cooperation (sharing of expensive tools such as tractors). Once financially covered, the relative construction costs decreased, and profitability of vegetable production increased with increasing usage period of high beds. Finally, the investment in high beds as an example for

improved crop management technologies increased net returns by 65 % compared to standard techniques (flat bed) after a period of three years.

High beds increased vegetable production in the rainy off-season. For Chinese cabbage it was shown that there is a great potential for high market prices in the off-season, so that these prices can more than compensate for oftentimes lower yields. Nevertheless, the risk of a complete crop failure in this season cannot completely be ruled out. However, avoiding of risk by relying on low-value field crops may not be guaranteed either: adverse weather conditions also negatively affected yields of two rice crops in the rainy season. The discrepancy between productivity and profitability of crops is another difficulty to face farmers in the introduction of improved management practices for off-season vegetable production. Alleviation of flooding stress by high beds increased chili yields manifold, but monetary returns and thus profitability remained low. This was due to a low market value or limited market acceptance of this crop. The choice of a suitable crop management technique has to match a suitable crop sequence and not vice versa.

(4) *Credit* costs did not influence profitability of vegetable production much. It was assumed that agricultural credits were freely accessible, but this was found not to be true in some rural communities in Asia (JANSEN *et al.* 1996*a*). Poor access to credit facilities or unavailability of loans and credits for vegetable production were seen as important constraints ripe for government intervention.

(5) Adoption of the N_{min}-*reduced method* saved quantity and cost of fertilizer. Returns from vegetable production were, however, reduced. Since fertilizer costs and also costs for pesticides comprised only a minor part of total production costs, it is understandable that farmers frequently use such inputs in irrational quantities to ensure maximum yields which over-compensate for the low additional costs. Government intervention (e.g. quality control of the vegetable produce, limits for groundwater contaminants) may be the only way to alleviate environmental hazards resulting from unobjective use of mineral fertilizers and farm-chemicals.

Governmental interventions should not be restricted to regulations. Promotion of knowledge and technologies concerning sustained high and environmentally sound vegetable production is an important consideration for countries where the food-sector is closely connected with the wealth of the population. Access to information, assistance, and training concerning locally adapted vegetable production technology

should be ensured for producers. Inputs and special funds to cover their capital costs should be made available to encourage farmers to invest in cropping technology.

V General Discussion

Increasing food production for the growing population in many tropical countries is an undisputed objective of the present and future (VON UEXKÜLL, 1995). Vegetables are an important commodity in food supply because they are an important source for nutrients and health (CHEN, 1995).

Except a limited number of locally adapted species, most commercially grown vegetables in the tropics are temperate-type. Tropical highlands are climatically more suitable for such species, but markets are distant and production of vegetables in those regions oftentimes creates tremendous environmental damage (MIDMORE *et al*. 1996). The population and, therefore, the demand for vegetables is expected to dramatically increase in the urban areas which are mostly located in the lowlands (SMIT, 1995). Concern for environmental damage to tropical highlands and the recognition of the future development of spatial distribution of the population has created the demand for increasing vegetable production in the tropical lowlands (RICHTER *et al*. 1995).

Climatic conditions in tropical lowlands pose several problems for economical production of temperate-type vegetables, such as abiotic factors (temperature, water, and nutrients) and biotic factors (pests and diseases). The severity of influence of these individual growth factors is not unique and constant over time. This is clearly expressed by the large seasonality in vegetable supply (ALI *et al*. 1994). Management of (assumed) production constraints in tropical vegetable production is often associated with contamination of produce and environment, and with degradation of agricultural soils (HUANG *et al*. 1989).

Growth of plants depends on the intensity of growth-factors and their interactions ("*Mitscherlich-model*"; KRUG, 1991). A factor which is below its critical level determines the growth of a plant. Only by elevating this "minimum-factor" further to its optimum, growth can be improved. Managing growth-factors other than the particular minimum-factor will have no effect on growth. However, if one growth-factor is optimized, another factor may become the minimizing element for growth and so on. If vegetable production is to be increased in tropical lowlands, it is primarily important

to identify the growth-factor(s) which limit productivity more decisively than other factors. This was one main objective of this study. In Chapter A it was concluded that stresses caused by suboptimum soil water conditions were closely related to yields of vegetables. Soil water was deficient during the dry seasons and excessive during the rainy seasons. However, the effect of excess soil water during the rainy season had an exaggerated effect on vegetable growth. In Chapter B, the effect of the growth-factor "soil water" was compared to the effect of "soil nitrogen" and it was concluded that soil water was the decisive element in limiting vegetable production and soil nitrogen was not. Other growth factors (particularly biotic factors) were not studied and handled optimal, but it appears that management of soil water must have first priority for increasing vegetable production in tropical lowlands. It could be argued that soil-related conditions at AVRDC would not represent conditions in fields of farmers. However, in intensive commercial production zones, soils have even been more intensively managed for already a much longer time. It appears, therefore, that the processes studied may have significant general relevance for vegetable production at present and in future.

For field-grown vegetables, no significant influence of soil nitrogen on yield was found (Chapter D). Given standard cultivation techniques, application of N-fertilizer could be dramatically reduced without seriously affecting yields (Chapter C). However, when the growth-factor "soil water" was better handled using permanent high beds, the growth-factor "soil nitrogen" became the minimizing element. Under these conditions it was concluded to reduce N-fertilizer on flat beds, but to increase application on high beds. This could help explain the frequent over-use of fertilizers in tropical vegetable production: farmers often consider soil nitrogen as the limiting input factor but actually it is soil water. He will over-dose fertilizers with the intention to improve his production. This will be without effect on production but will have negative consequences for the environment. A similar phenomenon my be true for the (over-) use of farm-chemicals.

When implementing crop management technologies to vegetable production in tropical lowlands, it must be recognized that many of such techniques have been developed under very different environmental conditions. If techniques (e.g. management of crop residues and green manure in this study) have been proven successful in one environment (e.g. in moderate climates), they may exert no or even detrimental

effects in another environment. This is particularly true for many tropical lowlands in which soils have long been modified to suit rice cultivation which is much different from cultivation of vegetables (Chapters A and B).

Permanent high beds were tested primarily for their potential to increase vegetable production under the difficult conditions during the rainy season. Compared to standard flat beds, they increased vegetable yields manifold during this season. High beds improved hydraulic conditions of soils under wet conditions. When the water table is close to the soil surface and the soil above is saturated, vertical infiltration diminishes as the gradient in moisture-potential between the upper and the lower soil layer approaches zero tension (HILLEL, 1980). In contrast to traditional flat beds, the deep furrows between high beds have much more capacity to drain and store water. They act as a drain into which excessive soil water flows along a horizontal hydraulic gradient. During the rainy season a sink, the furrows acted as a source to supply high beds with water during the dry season. However, irrigation proved crucial for vegetable production since these furrows could only supply a part of crop water needs.

Optimum dimensions of high beds depend primarily on regional rainfall conditions, and on irrigation facilities. Without irrigation, yields of vegetables decreased towards the center of high beds under both deficient and excessive soil water conditions. When rains usually proceed for prolonged times, narrower beds are more advantageous. Under weather conditions with a quick succession of heavy, short rainfalls and dry, sunny weather, wider beds are preferable.

In the rice based environment of tropical lowlands, root-growth characteristics varied not much among vegetable species. They accumulated above 40-cm soil depth, but were modified by high beds. This could be explained by the differences in soil water conditions between high and flat beds. Under dry soil conditions, roots of vegetable soybean elongated more profoundly to deeper soil layers in high beds. HEATHERLY (1980) stated that soybean required more roots when cultivated in dry soil. However, yields were lower than on flat beds, suggesting that to much photosynthate was diverted into root growth at the expense of yield. In more flood-prone flat beds, root systems were typically restricted to the uppermost soil layer during the rainy season. Adventitious rooting may have helped those crops to recover from flooding (JACKSON & DREW, 1984), but yields remained marginal.

The effects of permanent high beds on soil nitrogen must be viewed in the context

of the seasonal variations in soil nitrate governed by the seasonality in soil moisture. During the dry season soil nitrate accumulated. This process was observed in several tropical climates with distinct dry and rainy seasons by GREENLAND (1958) and REYNOLDS-VARGAS *et al.* (1994). Several processes may be responsible for this accumulation. Rapid and complete mineralization of ammonium may be one reason and it can be speculated that release and subsequent nitrification of clay-fixed ammonium (DRURY & BEAUCHAMP, 1991) played another role. Consequences for vegetable production in tropical lowlands are the cultivation of species with high nitrogen-absorbing capacity, and reduction of rates of N fertilizer. With the onset of the rainy season, the accumulated nitrate was quickly lost and remained low throughout this season. Ammonium fertilizer was nitrified slower. N fertilizer increased nitrate contents in the root zone of vegetables on flat beds. In high beds, application of N fertilizer did not increase soil nitrate in the root zone much, and less nitrate was found below the root zone. WESSELING (1974) stated that the efficiency of N fertilizer depends largely on drainage conditions. Soil water plays an important role in the recovery of soil nutrients by its effect on soil oxygen (BRAUN & ROY, 1983). Drainage was better and efficiency of N fertilizer was greater on high beds: applied N was effectively absorbed, vegetables produced much greater biomass and yield and, therefore, less nitrate was leached below the root zone.

Although permanent high beds are only one option to manage soil water, there are other factors associated with their potential for increasing vegetable production in the rainy season. (1) Permanent high beds are not a new invention: they are known to exist since ancient times, and are presently utilized in localized areas in the lowland tropics. Knowledge concerning this technology must not be newly developed, but is already available and can be immediately transferred to other areas. (2) Construction of high beds can meet the degree of availability of labor and mechanization. At a low level of mechanization, beds can be prepared by hand with only simple, locally made tools. At an advanced level, specially constructed equipment can substitute the requirement for hand-labor. In contrast to other approaches to manage soil water in tropical vegetable production, even this equipment can be produced locally. In Taiwan's extremely intensive vegetable "industry", special tools for preparing high beds have been developed, but other highly advanced techniques for water control such as

glasshouses, hydroponics, and drip irrigation systems are almost completely absent on commercial vegetable farms.

The "*N_{min}-reduced method*" was based on the N_{min}-method in Europe (WEHRMANN & SCHARPF, 1986). As a management technology to save N-fertilizer and reduce pollution of the environment, the method was only partly successful (Chapter C). When applied to the standard cultivation system (flat beds), 56 % of N fertilizer could be saved and leaching of N reduced without seriously reducing yields. There are similar findings with the N_{min}-method for vegetable farming in Germany (e.g. HÄHNDEL & ISEMANN, 1993). However, this was due to the accumulation of soil nitrate during the dry season, the greater susceptibility to flooding in the rainy season and the small root-mass of vegetables on those beds. Leaching of nitrate could be reduced on flat beds without seriously affecting yields. High bed technology largely eliminated flooding stress and improved rooting of vegetables. Greater biomass production and, hence, much better yields of vegetables on permanent high beds could not be sustained with the N_{min}-reduced method. It appears that technologies which improve growth and productivity of vegetables may have a more significant impact on reducing environmental pollution with nitrogen than N management itself. High bed technology improved productivity of vegetables, and thereby reduced pollution of the environment with nitrogen. Only on flat beds, the N_{min}-reduced method decreased application rates of N and leaching of nitrate, but yields of vegetables on those beds were marginal due to flooding. A better approach to improve N management could be to reduce fertilizer application rates by a certain percentage during periods when the amount of available N in the soil can partly or completely meet the demand of vegetables. Such simple approaches may be more practical than applying laborious and time-consuming technologies like the N_{min}-method to vegetable farms in tropical lowlands.

"*Integrated analysis of soil and plant nitrogen*" was only successful for determining optimum N-fertilization under controlled environmental conditions in a glasshouse (Chapter D). The Michaelis-Menten model of saturation kinetics (GEISSLER *et al*. 1981) was useful in relating nitrate in plant sap of petioles to soil nitrate (WESTCOTT *et al*. 1994). It was possible to determine the optimum fertilizer rate at

which yields and efficiency of fertilizer use was maximal. Greater application rates only resulted in luxury N-consumption (BLACKMER & SCHEPERS, 1994) without further increase in yield, but to accumulation of soil nitrate. Under field conditions, this nitrate will be subject to loss.

The methodology developed under glasshouse conditions could not be transferred to field-grown vegetables. Plant sap nitrate and soil nitrate data could not explain variations in crop yield. Difficulties arise with analysis of soil and plant nitrogen data to establish diagnostic criteria for N when other environmental factors inhibit crop growth apparently more than nitrogen. BEVERLY (1994) was unable to determine diagnostic criteria for potassium in sap of tomato seedlings since other factors limited growth more than the element under study. Data for asparagus (GARDNER & ROTH, 1989) illustrate a similar phenomenon: reductions in yield resulted from suboptimum water application rates despite sufficient sap N concentrations throughout the season. Such conditions limit the use of integrated analysis of soil and plant sap nitrate as a tool to manage N fertilization. In the field experiments, yield differences in vegetables were primarily due to different levels of stress caused by deficient or excessive soil water conditions. Limited availability of soil nitrogen was less detrimental. The tested N-management technology requires that soil nitrogen is the "minimizing" growth factor. This indicates that the technique may be restricted to high-tech production systems like soilless culture where other growth-factors like water and temperature can be perfectly controlled. Under such conditions, nitrogen will be the "minimum-factor" and can be managed accordingly.

On-farm "*management of crop residues and green manure*" is often considered an integral part of vegetable production. In this study (Chapter E) these assumptions were not confirmed for vegetable production in tropical lowlands. Negative effects on vegetable production could be clearly determined on the short term, and positive effects on the longer term were not much pronounced and only short-lived.

Crop residues are available in large quantities in vegetable production and contain significant amounts of nutrients. However, in a quick succession of vegetable crops, negative, soil-related effects of decomposing fresh residues in vegetables limit their use. Soils used for rice have usually low redox-potentials. When incorporating crop residues, soil nitrogen may be immobilized oxygen may be further depleted, and phytotoxic decomposition products may be produced. These detrimental effects are

immediately apparent. This may be the reason why farmers frequently just depose residues which can become a problem for public health and the environment. Municipal composting could be an alternative if supported or mandated by government.

Green manure as a full crop in rotation with vegetables cannot be afforded by small-scale vegetable farmers in tropical lowlands. Therefore, efforts have been made to intercrop green manure with vegetables as a live mulch (SARRANTONIO, 1992). However, there is a need to minimize interspecific competition (KANG *et al*. 1990). By changing the proportion and the spatial arrangement of live mulch and vegetable (RADOSEVICH & WAGNER, 1986), this competition could be reduced. However, incorporation of live mulch did not improve performance of vegetable crops. Soil nitrate was temporarily immobilized after mulch application (YAMOAH & MAYFIELD, 1990), and particularly when temperatures were cool (PATRICK *et al*. 1964). In the hot season release of N was more pronounced. Live mulch biomass was usually negatively correlated with vegetable yields on the short term (NICHOLSON & WIEN, 1983), but biomass of live mulch in one year was positively correlated with vegetable yields one year later (WARMAN, 1990). However, these positive effects did not last for more than a few crops (UTOMO *et al*. 1992). Effects of live mulch on soil nitrogen could not be detected, but there was indication that plant nutritional status was improved.

Positive results with green manure are oftentimes achieved when there is enough time and space for crop production, and when farm-inputs (i.e. fertilizers) are scarce. Under such extensive (subsistence) conditions, yields could be sustained for long times, but at apparently low levels. When vegetable production should be increased in spatially limited, highly populated tropical lowlands, these techniques are likely not the way to more resource-efficient and environmentally sound production. Better alternatives could be systems of municipal composting which could provide organic composts of good, controlled quality to a great number of vegetable producers. If such a system cannot be handled in a farm community, governmental intervention is called for. The immense quantities of organic city waste, organic end-products from industries, and crop residues from farms must be recycled for environmental reasons to improve health and quality of live for the community. Made available to farmers at affordable prices, such organic fertilizers could help in maintaining fertility and productivity of scarce agricultural land, and thereby offer the chance to reduce fertilizer consumption on commercial farms in the long run.

The *economic analysis of crop management technologies* confirmed the low profitability in rice production despite governmental interventions (PINGALI, 1992). Recent field studies for Nepal (JANSEN *et al*. 1996*a*) and Vietnam (JANSEN *et al*. 1996*b*) have shown that returns were greater in vegetable farms. This is confirmed since vegetable production was estimated to be five times more profitable than rice. Therefore, to improve farmer's income, complementation of field crops with high-value crops such as vegetables is of great importance. Vegetable production can be initiated at small scale close or distant to markets. However, with rising intensification, closeness to cities as the markets for supply of production factors and demand for the vegetable produce makes peri-urban regions more suitable for vegetable production in tropical lowlands (RICHTER *et al*. 1995).

Production factors were ranked according to their effect on overall profitability of vegetable production. Greatest profitability was achieved when family labor was utilized. Profitability sharply decreased when labor had to be hired. Saving of labor-input by mechanization of farm operations was ranked in second place. The appropriate choice of the cultivation system was the third most important factor for profitability of the vegetable farm. Permanent high beds had to be adopted to achieve greatest farm benefits. This benefit increased with increasing usage period. Construction costs were only a fraction of total production costs. It was more advantageous to choose traditional flat beds only when no family labor, no machinery, and no own capital was available to the farm business, an unusual scenario for vegetable farms. Credit costs did not influence profitability of vegetable production much, but they can become a problem when they are not freely accessible as in some rural communities in Asia (JANSEN *et al*. 1996*a*). The N_{min}-reduced method saved cost of fertilizer. However, the yield reductions over-compensated for these gains since costs for fertilizers were only a very small fraction of total production costs. For promotion of such technologies to improve public health and protect the environment, governmental intervention is called for.

Under the assumption that vegetable production must be increased in tropical lowlands, the results of this study show the importance of detecting the factors which limit vegetable production most seriously. Excessive soil water conditions during the tropical rainy season appear as the primary reason for deficits in vegetable supply and

consumption during that season. Therefore, efforts to improve vegetable production must be preferably directed towards overcoming water stress during the rainy season. Some genetic tolerance to waterlogging has been identified in crop breeding programs and biotechnology may offer pathways to induce flood-tolerance in vegetables, but, until proven successful, management technologies will be the only short-term way to overcome the deficit in vegetable production. Permanent high beds were analyzed as one suitable example of management techniques to tackle such production constraints. By significantly increasing vegetable production, the efficiency of use of external inputs (fertilizer) was improved, and thereby pollution of the environment prevented. Considering profitability of vegetable enterprises, health of the population, and environmental protection, crop management technologies are low-tech, affordable instruments to improve vegetable production and, therefore, wealth and quality of life for the dense populations in tropical lowlands.

VI Summary

From 1992 to 1995, experiments were conducted at the Asian Vegetable Research and Development Center (AVRDC) to test crop management technologies for their agronomic, ecological, and economical suitability to improve vegetable production in tropical lowlands. It was emphasized to develop practices for increasing production during the tropical rainy season when vegetable supply is most deficient. Technologies included: (1) permanent high beds, (2) the "N_{min}-reduced method", (3) the "integrated analysis of soil and plant nitrogen", and (4) management of crop residues and green manure. Parameters studied during the 43-month crop sequence of 13 vegetable crops (6 species) and 7 aquatic field crops (3 species) were: yield, soil water, soil and plant nitrogen, root distribution, market supply and price, and production costs.

Results can be summarized as follows:

A Effects of Permanent High beds on Vegetable Production — Soil Water

- Permanent high beds improve hydraulic conditions of soils under wet conditions. The furrows between high beds act as a sink to drain excess water during wet periods and can act as a source to supply beds with water during dry periods.
- Optimum dimensions of high beds depend on regional rainfall conditions and irrigation facilities. Their width may range from less than one meter to several meters.
- Yields of vegetables year-round were closely related to "water stress" caused by either excessive or deficient soil water. This effect was exaggerated under flooded soil conditions during the rainy season.
- Root systems of vegetables varied not much among species and accumulated above 40-cm soil depth. In permanent high beds, root density was greater and roots elongated more profusely into deeper soil layers.

B Effects of Permanent High beds on Vegetable Production — Soil Nitrogen

- Contents of soil nitrate followed the seasonal variations of soil moisture. Nitrate was low during the rainy season and accumulated during the dry season until the begin of the rainy season when it was quickly lost.
- Several processes may be responsible for the accumulation of nitrate during the dry season.
- The biological process of nitrification of ammonium from fertilizer was rapid and complete during the dry season, but proceeded slower during the rainy season.
- The seasonality of soil nitrogen should have significant consequences for vegetable production in tropical lowlands. Fertilizer rates should be reduced and vegetables with a high nitrogen-absorbing capacity should be cultivated during the dry season when soil nitrogen is high.
- Injury in vegetables by soil ammonium could not be detected.
- Soil nitrogen was more effectively absorbed by vegetables on permanent high beds. Therefore, less nitrogen was leached below the root zone.
- The effects of soil water affected vegetable growth more decisively than did soil nitrogen.

C Effects of N Management on Vegetable Production — N_{min}-Reduced Method

- The "N_{min}-reduced method" considerably lowered the amounts of N fertilizer applied.
- On traditional flat beds, yields were not reduced, but leaching of nitrogen was restricted.
- On permanent high beds, yields were significantly reduced. Particularly during the rainy season, vegetables on those beds had a greater capacity to absorb nitrogen for producing much better biomass and yield.

D Effects of N Management on Vegetable Production — Integrated Analysis of Soil and Plant Nitrogen

- The "integrated analysis of soil and plant nitrogen" was successful under controlled environmental conditions in a glasshouse, but not for field-grown vegetables.
- In the glasshouse, analyses of nitrate in soil and plant sap were suitable to determine (1) optimum concentrations of plant nitrogen at different growth stages, (2) optimum contents of soil nitrogen, and (3) optimum rates of N-fertilizer.
- Under field conditions, analyses were not successful since nitrogen was apparently not a "minimum" growth factor.

E Effects of Crop Residue and Green Manure Management on Vegetable Production

- Application of fresh crop residues did not exert positive effects on vegetable growth. Non-leguminous residues negatively affected germination and yield of subsequent vegetables.
- Application of green manure exerted a negative short-term effect on vegetable growth: soil nitrogen was immobilized particularly when temperatures were cooler.
- There was only a small and short-lived positive effect of green manure as live mulch on vegetable production over the longer time span.
- Recycling crop residues and applying them to vegetable fields as mature composts could be a better alternative than applying fresh residues and green manure.

IV Economy of Crop Management Technologies

- Vegetable production in tropical lowlands was estimated to be as much as five times more profitable than rice production on the same piece of land.
- The profitability of crop management technologies primarily depended on the availability of labor and on the level of mechanization. Compared with the total expenditure of a vegetable farm, credit-costs and costs for fertilizers were only minor.
- Permanent high beds were profitable under economic conditions since construction costs are not excessive within the total costs of high-value vegetable production.
- Technologies for saving fertilizers and improving environmental conditions were not economical. This calls for governmental intervention.

VII Zusammenfassung

Von 1992 bis 1995 wurden beim Asian Vegetable Research and Development Center (AVRDC) in Taiwan Untersuchungen zur pflanzenbaulichen, ökologischen und ökonomischen Eignung von Anbautechnologien zur Verbesserung der Gemüseproduktion in tropischen Tiefländern durchgeführt. Ein Schwerpunkt lag dabei auf der Entwicklung von Praktiken zur Steigerung der Gemüseproduktion während der tropischen Regenzeit, in der Angebot und Verzehr am geringsten ist. Technologien bestanden aus: (1.) Hochbeetkultivierung, (2.) einer modifizierten N_{min}-Methode zum verringerten Einsatz von Stickstoff, (3.) der integrierten Analyse von Stickstoff im Boden und in der Pflanze sowie (4.) der Handhabung von Ernterückständen und Gründüngung. Während der 43-monatigen Fruchtfolge von 13 Gemüsekulturen (6 Gemüsearten) und 7 Wasserkulturen (3 Feldfrüchte) wurden Erträge, Bodenwasser, Boden- und Pflanzenstickstoff, Wurzelverteilung, Marktangebot und -preis und Produktionskosten bestimmt.

Die erzielten Ergebnisse können folgendermaßen zusammengefaßt werden:

A Der Einfluß von dauerhaft angelegten Hochbeeten auf die Gemüseproduktion — Bodenwasser

- Hochbeete verbessern den Wasserhaushalt von nassen Böden im tropischen Tiefland. Die Furchen zwischen Hochbeeten stellen bei nassen Bodenverhältnissen eine Senke für überschüssiges Bodenwasser dar und können bei trockenen Bodenverhältnissen als Wasserspeicher zur Bewässerung dienen.
- Optimierung der Dimensionen eines Hochbeetes hängt von den lokalen Regenverhältnissen und den vorhandenen Bewässerungsanlagen ab. Deren Breite kann von weniger als einem Meter bis zu mehreren Metern reichen.
- Erträge ganzjähriger Gemüseproduktion waren eng mit „Wasserstress", d.h. überschüssigem und mangelndem Bodenwasser, korreliert. Dieser Einfluß war besonders bei staunassen Bodenverhältnissen während der Regenzeit kritisch.
- Die Wurzelsysteme der verschiedenen Gemüsearten waren ziemlich einheitlich und auf die oberen 40 cm Bodentiefe beschränkt. In Hochbeeten war die Wurzeldichte insgesamt größer und Wurzeln reichten in tiefere Bodenschichten als in Flachbeeten.

B Der Einfluß von dauerhaft angelegten Hochbeeten auf die Gemüseproduktion

— Bodenstickstoff

- Gehalte an Bodennitrat korrelierten in etwa mit den saisonalen Schwankungen der Bodenfeuchte. Bodennitrat war während der Regenzeit gering und sammelte sich im Verlauf der Trockenzeit an. Bei Einsetzen der Regenzeit war es dann schnell verloren.
- Verschiedene Prozesse sind für die Ansammlung von Bodennitrat während der Trockenzeit verantwortlich.
- Der biologische Prozeß der Nitrifizierung des Ammoniums aus Stickstoffdünger war rasch und vollständig während der Trockenzeit und vollzog sich langsamer während der Regenzeit.
- Die Saisonalität in der Verfügbarkeit von Bodenstickstoff sollte deutliche Konsequenzen für die Gemüseproduktion im tropischen Tiefland haben. Während der Trockenzeit sollte die Stickstoffdüngung reduziert werden und Gemüse mit einer starken Aneignungsfähigkeit für Stickstoff angebaut werden.
- Gemüse wurde nicht durch Bodenammonium geschädigt.
- Vorhandener Bodenstickstoff wurde effizienter von den Gemüsekulturen auf Hochbeeten aufgenommen. Daher blieben Auswaschungsverluste gering.
- Der Einfluß von „Bodenwasser" hat das Wachstum von Gemüse entschiedener geprägt als die Verfügbarkeit von Bodenstickstoff.

C Der Einfluß von gezielter Stickstoffdüngung auf die Gemüseproduktion — N_{min}-Methode

- Die modifizierte N_{min}-Methode senkte die Stickstoffdüngemengen erheblich.
- Auf herkömmlichen Flachbeeten wurden die Gemüseerträge durch diese Methode nicht gefährdet aber die Auswaschungsverluste von N reduziert.
- Auf Hochbeeten sanken die Erträge, da die Gemüsearten besonders während der Regenzeit Stickstoff besser aufnehmen konnten und viel mehr Biomasse und Ertrag produzierten.

D Der Einfluß von gezielter Stickstoffdüngung auf die Gemüseproduktion — Integrierte Analyse von Stickstoff im Boden und in der Pflanze

- Die Analyse von Boden- und Pflanzenstickstoff war nur unter den kontrollierten Anbauverhältnissen eines Gewächshauses bei einer Gemüseart erfolgreich. Sie war nicht auf den Feldgemüsebau übertragbar.
- Im Gewächshaus konnten (1.) optimale Konzentrationen von Nitrat im Pflanzensaft zu verschiedenen Wachstumsstadien, (2.) optimale Nitratgehalte im Boden und (3.) die optimalen Stickstoffdüngemengen bestimmt werden.
- Auf Freilandverhältnisse waren die Analysen nicht anzuwenden, da dort Stickstoff offensichtlich kein „minimierender" Wachstumsfaktor war.

E Der Einfluß der Handhabung von Ernterückständen und Gründüngung auf die Gemüseproduktion

- Einbringen von frischen Ernterückständen führte zu keinerlei positivem Effekt auf nachfolgende Gemüsekulturen. Ernterückstände von Nichtleguminosen beeinträchtigten die Keimung und den Ertrag nachfolgender Gemüsearten.
- Einbringen von Gründüngung führte zu einem negativen Kurzzeiteffekt des Gemüsewachstums: Besonders bei kühleren Temperaturen wurde Bodenstickstoff zu lange immobilisiert.
- Längerfristig führte Gründüngung als „lebender Mulch" nur zu einem geringem und zeitlich sehr begrenztem positivem Effekt.
- Wiederverwenden von Ernterückständen als gut ausgereifte Komposte könnte eine bessere Alternative zu frisch eingebrachten Ernterückständen und Gründüngung sein.

IV Die Ökonomie von Anbautechnologien

- Gemüseproduktion im tropischen Tiefland kann fünfmal mehr profitabel als Reisanbau in dieser Region sein.
- Der ökonomische Vorteil von Anbautechnologien hängt in erster Linie mit den Arbeitskosten und der Mechanisierung des Anbaus zusammen. Kredite und Düngemittel werfen relativ geringe Produktionskosten auf.
- Basierend auf ökonomischen Annahmen sind Hochbeete lohnend, da ihre Konstruktionskosten in der generell kostenintensiven Produktion von Gemüse nicht übermäßig hoch sind.
- Anbautechnologien zur Einsparung von Düngemitteln und zur Verbesserung der Umweltverhältnisse sind nicht ökonomisch. Hier sind staatliche Eingriffe notwendig.

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