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Managing Nitrogen Fertilization for Year-Round Vegetable Production in Paddy Rice Fields

Stickstoffversorgung von Gemüse bei Ganzjahresproduktion in Naßreisfeldern

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Introduction

Permanent high bed cultivation is known to exist in many peri-urban lowland production zones in Asia ranging from China CHIC 1987, PLUCKNETT and BEEMER 1981) to India (SINGH and GANGWAR 1989).

At present, heavy applications of N fertilizer are common practice in many of these and other intensive vegetable production areas in the Tropics and Subtropics. Increasing concern for the negative consequences of over-fertilization, particularly regarding nitrate contamination of ground water and potentially harmful high nitrate contents in vegetables has led to the demand for the development of N-management strategies to improve fertilizer efficiency. One approach to improve N management is to fine-tune the amount of N fertilizer to better synchronize availability with plant requirements.

Widely introduced to Central Europe is the N_{min}-method that essentially depends on the measurement of soil N and takes into account crop needs.

The limited use of N_{min} in commercial fields is attributed more to the immense requirement for time and labour to sample and analyse the soil than the doubt that the soil analysis data would not reliably represent plant nutritional status (MATTHÄUS et al. 1994). The first part of this study deals with the experience of the N_{min}-method in a 14-month, 5-crop continuous year-round vegetable cropping sequence in the subtropical environment of Southern Taiwan, where crops were either grown on traditional flat beds, or on permanent high beds in previous paddy rice fields.

If the N_{min}-method is too slow and expensive, what other method may be suitable and accurate enough to improve N fertilizer management sufficiently (HARTZ 1994). Plant tissue analysis is regarded helpful in indicating plant nutrition status and forecasting crop yields, but conventional tissue tests, as for the N_{min}-method, create significant costs and time lag between sampling and result.

A new promising analytical procedure is to measure NO_3-N concentration in fresh petiole sap (SN-test; sap nitrate

Table 1. Summary of cultural details
Übersicht über den Versuchsaufbau

Crop	Chinese cabbage	Chili	Carrot	Vegetable soybean	Chinese cabbage
Cultivation period	May-Jun '93	Jun-Nov '93	Dec-Feb '93/94	Mar-May '94	Jun-Jul '94
Plant distance (cm • cm)	50 • 60	50 • 60	25 • 05	50 • 05	50 • 40
Plant density (pla./m^2)					
flat bed system	3.33	3.33	80.00	40.00	3•33
high bed system	3.33	3.33	80.00	40.00	5.00
N fertilization					
WAS/WAT	0^1 2 4	0^1 4 8 12	0 7	0 2 4	0 2 4
standard rate (kg N/ha)	60 30 30	50 50 50 50	60 60	20 20 20	60 30 30
N_{min}-method (kg N/ha)	0 30 30	20 50 50 50	0 0	0 0 0	20 0 0

[1] N_{min}-method only for basal fertilizer application (WAS/WAT = weeks after seeding/weeks after planting)

test), a method that has proved to be highly correlated with dry tissue NO_3-N concentrations in several vegetable species (HARTZ et al. 1993). Since nutrient concentrations decline most quickly in rapidly expanding new tissues (BURNS 1991), and the petiole acts as a storage and transport organ for nitrate-N, the petiole of recently matured leaves is a sensitive indicator of plant N status (VITOSH and SILVA 1994) and N nutrition (PRASAD and SPIERS 1984).The goal is to determine the minimum level of petiole sap NO_3-N associated with maximum yield (COLTMAN 1989), a "critical petiole NO_3-level" above which a crop would be adequately supplied with N and no additional N fertilizer would be needed, and below which the crop would be deficient in N nutrition and would require additional N fertilizer to ensure maximum yield.

At present, the calibration of the method poses the most significant hindrance to practical application since diagnostic standards for critical NO_3-N concentrations in plant sap are still lacking (BEVERLY 1994). Vegetable extension institutions in Europe (MATTHÄUS et al. 1994), and the US (HOCHMUTH 1992) are, however, beginning to use this new technology and are presenting first guidelines to the commercial grower. New, portable nitrate-selective electrodes and quantitative reflectometric analysis procedures for test strips make it much easier to achieve reliable results.

The objective of the second part of this study is to describe a model that integrates (1) soil N status (soil NO_3-N), (2) crop N status (petiole sap NO_3-N), and (3) crop yield response to provide a theoretical background for further studies of its kind, and to apply this model to two field-grown vegetable crops, vegetable soybean and Chinese cabbage, cultivated either on flat beds or on permanent high beds.

Materials and Methods

N_{min}-study

In spring 1993, an integrated permanent high bed – deep furrow system was laid out and constructed in a randomized 3-factor split-split block design with 4 replications. Treatments included: (1) high bed width, (2) legume green manure living mulch, and (3) N fertilization method. Results on the first two experimental factors will not be reported here. The N fertilization method consisted of 2 levels, (1) traditional (standard) N fertilizer input, and (2) N_{min}-method The two levels of this treatment were additionally randomized in 4 replications on 1.5 m wide flat beds to represent a control to the permanent high beds.

In a 14-month continuous year-round vegetable cropping sequence, summer rainy season crops consisted of Chinese cabbage (*Brassica pekinensis* (Lour.) Rupr.; variety ASVEG No.1', AVRDC) and chili (*Capsicum annuum* L.; variety 'Hot Beauty', Known You Seed Co.), whereas carrot (*Daucus carota* L. ssp. *sativus* (Hoffm.) Arcang.; `Red Judy', Known You Seed Co.) and vegetable soybean (*Glycine max.* (L.) Merr; variety AGS 292', AVRDC) were grown during the dry subtropical winter months. Aquatic crops cultivated in the continuously flooded furrows were taro (*Colocasia esculenta* (L.) Schott) and rice (*Oryza saliva* L.).

In the place of single rows for direct sown vegetable soybean and the pre-nursed and transplanted crops Chinese cabbage and chili, carrot was sown in paired rows. Dimensions of cultivation systems and plant rectangularity are presented in figure 1, and other cultural details are summarized in table 1.

All nitrogen was applied as ammonium sulphate ($(NH_4)_2SO_4$), an inexpensive and readily available N fertilizer source.

Soil N_{min} was measured before each N fertilizer application by sampling soil 30 cm deep in every N_{min}-treatment plot. Extracted 1: 2 by volume in 0.8% KCl water solution, samples were analyzed for NO_3 by use of Merck's RQflex reflectometer and Reflectoquant nitrate analytical test strips. N application rate for the N_{min}-treatment was calculated by subtracting the average N_{min}-value from the traditional N application rate. All other cultural practices were standard.

Since not all experimental treatments are reported in this study, statistical comparisons (mean comparisons within and between main factors "N fertilization method" and "cultivation system") were performed using orthogonal contrasts.

Integrated study of soil N, plant N, and crop yield

During the 1994 crops of vegetable soybean and Chinese cabbage, soil NO_3 and plant nitrate data were also collected at weekly intervals. Soil was sampled for 0–30 cm and 30

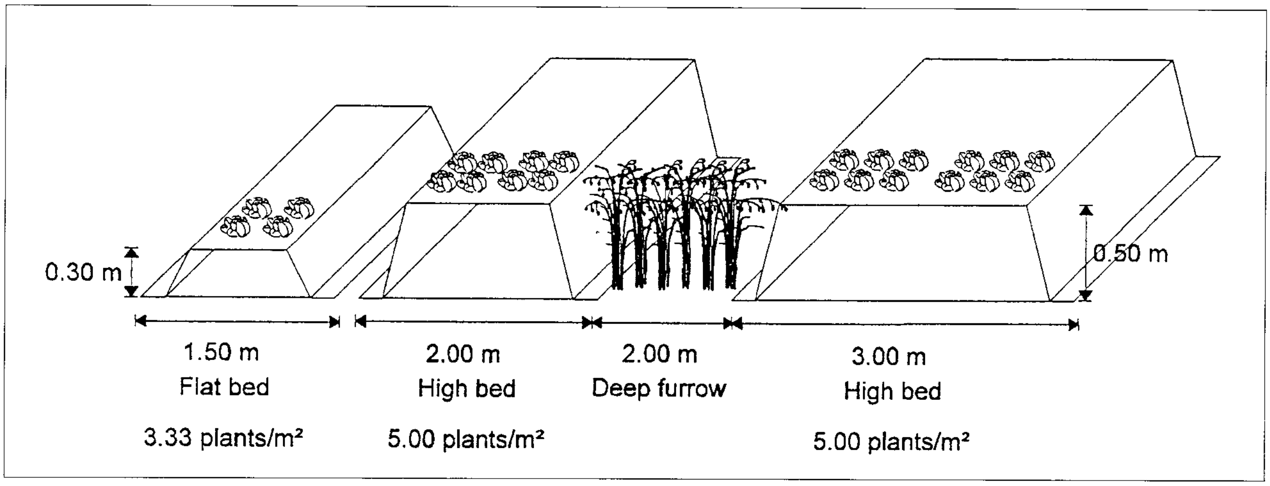


Fig. *1.* Dimensions of cultivation systems and plant rectangularity
Pflanzsysteme auf verschiedenen Hoch- und Flachbeetformationen

60 cm layers in 4 flat bed plots and 12 high bed plots. Petioles were collected from about 8 newly expanded leaves per plot for vegetable soybean and 5 midribs of recently matured leaves per plot for Chinese cabbage. Petiole sap was extracted by use of a small hand garlic press, and the sap diluted with deionized water to fit the range of the Reflectoquant test strips (5–225 ppm), for NO_3-N analysis by the RQflex.

To integrate soil N status, crop N status, and crop yield response, a functional relationship model was chosen which makes sense from theoretical and biological points of view and which was sufficiently well correlated with the data. The most widely used model in scientific publications is the polynomial approach ($V=a+b\bullet S+c\bullet S^2$ where V=crop yield, S = soil or plant N status; APOLINARES and RECEL 1994, FANG et al. 1994, CHAIWANAKUPT et al. 1994). In contrast, the Michaelis-Menten model of saturation kinetics de-scribes the velocity of an enzyme-mediated reaction as a function of substrate concentration (GEISSLER et al. 1981; figure 2). Analogous to the *Michaelis-Menten* model, the relationships (1) plant sap nitrate = f(soil nitrate), (2) crop yield = f(plant sap nitrate), and (3) crop yield =f(soil nitrate) were fitted to the hyperbolic model:

$$V = (V_{max} \bullet S) / (K_m + S)$$

where: V = plant sap nitrate concentration or crop yield, Vmax=(constant) upper limit for V, S = soil nitrate concentration or plant sap nitrate concentration, and K_m = (Michaelis constant) affinity for S.

In an earlier study by WESTCOTT and KNOX 1994 the relationship plant sap nitrate = f(soil nitrate) was well established for potato and peppermint. For the present analysis, however, since field experiments were not specially laid out for this purpose (N fertilizer rates were not systematically varied), it was expected that the regression equations would not provide very accurate predictions.

Yield as a function of soil N is usually poorly correlated. Integration of (1) yield = (A • plant NO_3-N)/(B + plant NO_3-N) and (2) plant NO_3-N = (a • soil NO_3-N)/(b + soil NO_3) results in: ((Aa/B+a) • soil NO_3-N)/((Bb/B+a) + soil NO_3-N). Comparison of this estimated function with the regression equation of yield = f(soil NO_3-N) can function as a control to predict whether the mutual relationship of hyperbolic dependencies is sufficiently determined. Using the polynomial approach instead would result in a 4th-order polynomial function, implausible and unsuitable from a theoretical and practical standpoint.

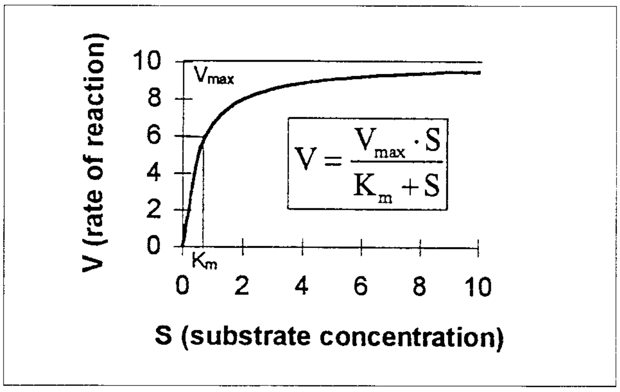
Results

N_{min}-study

The cultivation system was much more influential on productivity than the N fertilization regime throughout the 14-month cropping sequence (table 2). This tendency was at the same time much more pronounced for marketable yields than for total biomass production. Yields of the standard fertilization treatment on high beds surpassed those on flat beds by 58 %, 240 %, and 161 % for the summer crops of Chinese cabbage and chili 1993, and Chinese cabbage 1994. Winter season crop yields of carrot and vegetable soybean were, however, only slightly (8 % and 14 %) reduced compared to flat bed cultivation.

Soil N_{min} contents were very similar in flat bed and high bed systems during the rainy season summer crops (table 2). In the dry season, however, high soil nitrification rates in both cultivation systems resulted in N_{min}-concentrations that in the most part largely exceeded requirements of both crops of carrot and vegetable soybean. Very obvious is the accelerated mineralization potential on the flat beds during that season. Consequently, no additional N fertilizer was ap-

Fig. 2. The Michaelis-Menten curve
Kurve des Michaelis-Menten Modells



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

Table *2*. Influence of N_{min} fertilization method and cultivation system on vegetable yields
Der Einfluß von Stickstoffdüngung über N_{min}-Steuerung und zwei Kultursystemen auf Gemüseerträge während der Regen- und Trockenzeit

Crop	Chinese cabbage			Chili			Carrot			Vegetable soybean			Chinese cabbage		
Cultivation period	May-June 1993			June-November 1993			December-February 1993/94			March-May 1994			June-July 1994		
N_{min}															
Flat bed system	43[1] kg N/ha			30[1] kg N/ha			345 kg N/ha			214 kg N/ha			135 kg N/ha		
High bed system	60[1] kg N/ha			34[1] kg N/ha			177 kg N/ha			137 kg N/ha			131 kg N/ha		
Fertilization															
Traditional fertilization	120 kg N/ha			200 kg N/ha			120 kg N/ha			60 kg N/ha			120 kg N/ha		
N_{min} method	60 kg N/ha			180 kg N/ha			0 kg N/ha			0 kg N/ha			20 kg N ha		
Biomass (kg/m²)	Flat bed system	High bed system	*P* level	Flat bed system	High bed system	*P* level	Flat bed system	High bed system	*P* level	Flat bed system	High bed system	*P* level	Flat bed system	High bed system	*P* level
Traditional fertilization	2.97	3.37	0.07	0.98	1.62	< 0.01	2.41	2.31	0.83	2.16	1.80	0.01	2.76	4.16	< 0.01
N_{min} method	3.06	3.42	0.10	0.80	1.46	< 0.01	2.52	2.18	0.41	1.96	1.69	0.04	1.80	3.86	< 0.01
P level	0.72	0.77		0.27	0.19		0.81	0.70		0.15	0.29		0.04	0.08	
P level input	0.66			0.09			0.86			0.09			0.01		
P level system	0.02			< 0.01			0.46			< 0.01			< 0.01		
Marketable yield (kg/m²)	Flat bed system	High bed system	P level	Flat bed system	High bed system	P level	Flat bed system	High bed system	P level	Flat bed system	High bed system	P level	Flat bed system	High bed system	P level
Traditional fertilization	1.37	2.16	< 0.01	0.22	0.75	< 0.01	1.29	1.20	0.70	1.26	1.11	0.09	0.75	1.96	< 0.01
N_{min} method	1.49	2.22	< 0.01	0.20	0.63	< 0.01	1.40	1.17	0.33	1.20	1.06	0.12	0.19	1.22	< 0.01
P level	0.44	0.57		0.88	0.16		0.68	0.88		0.47	0.42		0.10	< 0.01	
P level input	0.36			0.22			0.91			0.28			< 0.01		
P level system	< 0.01			< 0.01			0.33			0.02			< 0.01		

[1] N_{min} method only for basal fertilizer application

plied in the N_{min} treatment. No significant yield differences were finally recorded between N fertilization regimes for these cool season vegetables.

The tendency for reduced N fertilization to become a more critical factor for crop production when yields reach higher levels can be summarized from summer crops of chili (1993) and Chinese cabbage (1994): With chili yields around 0.21 kg/m^2 on flat beds the orthogonal comparison between fertilizer treatments is far from significant (P= 0.88). Higher yields of 0.70 kg/m^2 on high beds come closer to significance (P= 0.16). For Chinese cabbage in 1994, low yields of 0.75 and 0.19 kg/m^2 did not differ on flat beds (P = 0.10) but did on high beds (1.96 and 1.22 kg/m^2; P<0.01).

No interactions were found between the main factors cultivation system and fertilization method for biomass production and yield. In other words, higher N fertilizer application did not overcome the disadvantageous crop environment of the commonly used flat planting beds on summer vegetable production.

Over all, N-fertilization for individual crops was reduced by up to 100% and a total of 360 kg N (42% of the traditional rate) was saved in a 14-month continuous vegetable cropping sequence by use of the N_{min}-method. Significant loss of yield due to the reduced N fertilization was only observed in the 1994 Chinese cabbage crop when grown on high beds. The yield reduction occurred in the second harvest, after a first harvest that showed no yield differences between traditional N fertilization and N_{min}-method (P = 0.79). Heavy typhoon rain between harvests may have diluted or leached out plant available nitrogen essential for head formation. This thesis is supported by less pronounced differences in total biomass at the second harvest (P=0.08).

Integrated study of soil N, plant N, and crop yield

Vegetable soybean

The most satisfactory fit for yield and nitrate was obtained at 4 WAS (weeks after seeding) when plants set flowers and the first side dressing is applied. While the fit was good for the regression plant sap NO_3 = f(soil NO_3), crop yield was only poorly related to soil nitrate content (0-60 cm depth; table

Table 3. Regression equations for the hyperbolic relation of soil NO_3 (0–60 cm), plant sap NO_3, and yield of vegetable soybean and Chinese cabbage grown on flat beds and permanent high beds

Ergebnisse der Regressionsanalysen für hyperbolische Relation von Boden- und Pflanzensaft-Nitratwerten sowie Erträge von Gemüsesojabohne und Chinakohl auf Flach- und Hochbeeten

Function type	Flat bed system		High bed system	
	Equation[1]	r^2	Equation[2]	r^2
Vegetable soybean				
plant NO_3 = f(soil NO_3)	V = (2751* •S)/(115$^{n.s.}$+S)	0.89$^{n.s.}$	V = (4142**•S)/(62**+S)	0•53'
yield = f(plant NO_3)	V = (1.46*•S)/(299$^{n.s.}$+S)	0.50$^{n.s.}$	V = (2.12*•S)/(3667*+S)	. 0.45"
yield = f(soil NO_3)	V = (1.30*•S)/(115$^{n.s.}$+S)	0.33$^{n.s.}$	V = (1.10**•S)/(24$^{n.s.}$+S)	0.17$^{n.s.}$
estimated function				
yield = f(soil NO_3)	V = (1.32•S)/(11+S)		V = (1.12•S)/(29+S)	
Chinese cabbage				
plant NO_3 = f(soil NO_3)	V = (7910$^{n.s.}$•S)/(173$^{n.s.}$+S)		V = (4584$^{n.s.}$•S)/(70**+S)	0.54'
yield = f(plant NO_3)	V = 7.65$^{n.s.}$•S)/(5978$^{n.s.}$+S)	0•82$^{n.s.}$	V = (9.89$^{n.s.}$•S)/(2721**+S)	0.51**
yield = f(soil NO_3)	V = (5.51**•S)/(112**+S)	0.99**	V = (4.63**•S)/(8$^{n.s.}$+S)	0.04$^{".s.}$
estimated function				
yield = f(soil NO_3)	V = (4.36•S)/(75+S)		V = (6.21•S)/(26+S)	

^{1}3 df; ^{2}11df

** sign. at 1% level; sign. at 5% level; $^{n.s.}$not sign.

3). Scatter plots in figure 3 illustrate significant differences between cultural systems for ability to take up available soil nitrate and to reduce this absorbed NO_3 efficiently to amino acids. Although plant sap nitrate accumulation was significantly higher for vegetable soybean grown on high beds, these higher concentrations resulted only in relatively low yields compared to the crop grown on flat beds.

Regression equations for marketable yield as a function of plant NO_3-N overestimated yield potentials. Although low in r^2 and P, estimated functions of yield versus soil NO_3 predicted upper limits of productivity that were almost precisely realized by the crop.

Small differences between yield and calculated yield potential suggest that soil N was not a factor limiting growth of this crop, irrespective of cultivation system. This is confirmed by a lack of significant differences in yield between N_{min}- and standard fertilization method (table 2). Differences can be explained by excessive root growth particularly in the early growth stages on the expense of assimilatory leaf area (as indicated by crop cover and root distribution, data not shown), leading to a delay in crop maturity.

Chinese cabbage

Soil nitrate and plant sap nitrate fitted best to gross yield data when collected 4 WAT (weeks after transplanting), before application of the second side dressing. Marketable yield of Chinese cabbage during the rainy season is largely affected by soft rot *(Erwinia carotovora)* and poor head formation. Soil and plant analysis cannot account for these losses.

In contrast to the vegetable soybean crop, scatter plots of plant sap nitrate versus soil nitrate (figure 3) show that soil nitrate uptake of crops grown on either flat beds or high beds was not different, whereas efficiency of transformation of absorbed NO_3 to biomass (yield = f(plant NO_3)) was. With similar NO_3-concentrations in plant sap, Chinese cabbage yields were much better on high beds than on flat beds. The regressions plant sap nitrate = f(soil NO_3) produced upper limits for plant sap nitrate concentrations that were distinctly higher than those measured in the crop. The same is true for the relationship yield = f(plant NO_3). Regressions indicate yield potentials in case of higher plant sap nitrate concentrations. Soil nitrate content at the end of the cultivation period resulted in sub-optimum plant sap nitrate levels that were possibly too little to support maximum yields. If the higher plant sap nitrate concentrations as recorded 2 WAT (4473 ppm in high beds; 5293 ppm in flat beds) were maintained, it may have been possible to achieve much better yields.

Discussion

Level of soil N_{min}-concentration depended largely on sea-son. High nitrification potential was evident particularly for the flat bed system during the dry winter season. Much less plant biomass was produced on flat beds compared to high beds during the preceding rainy season. Thus, since N fertilizer application rates were the same, much less N was removed from the soil system during that season when the soil is wet and partially anaerobic during most of the time. Nitrification of ammonium fertilizer is largely inhibited under anaerobic conditions, under which NH_4 is easily immobilized by soil microbes or fixed to clay minerals (DRURY and BEAUCHAMP 1991). Following drying of the soil in winter and intensive aeration through management (e. g. bed construction), this immobilized or fixed N obviously reappeared in the oxidized N form, leading to immense

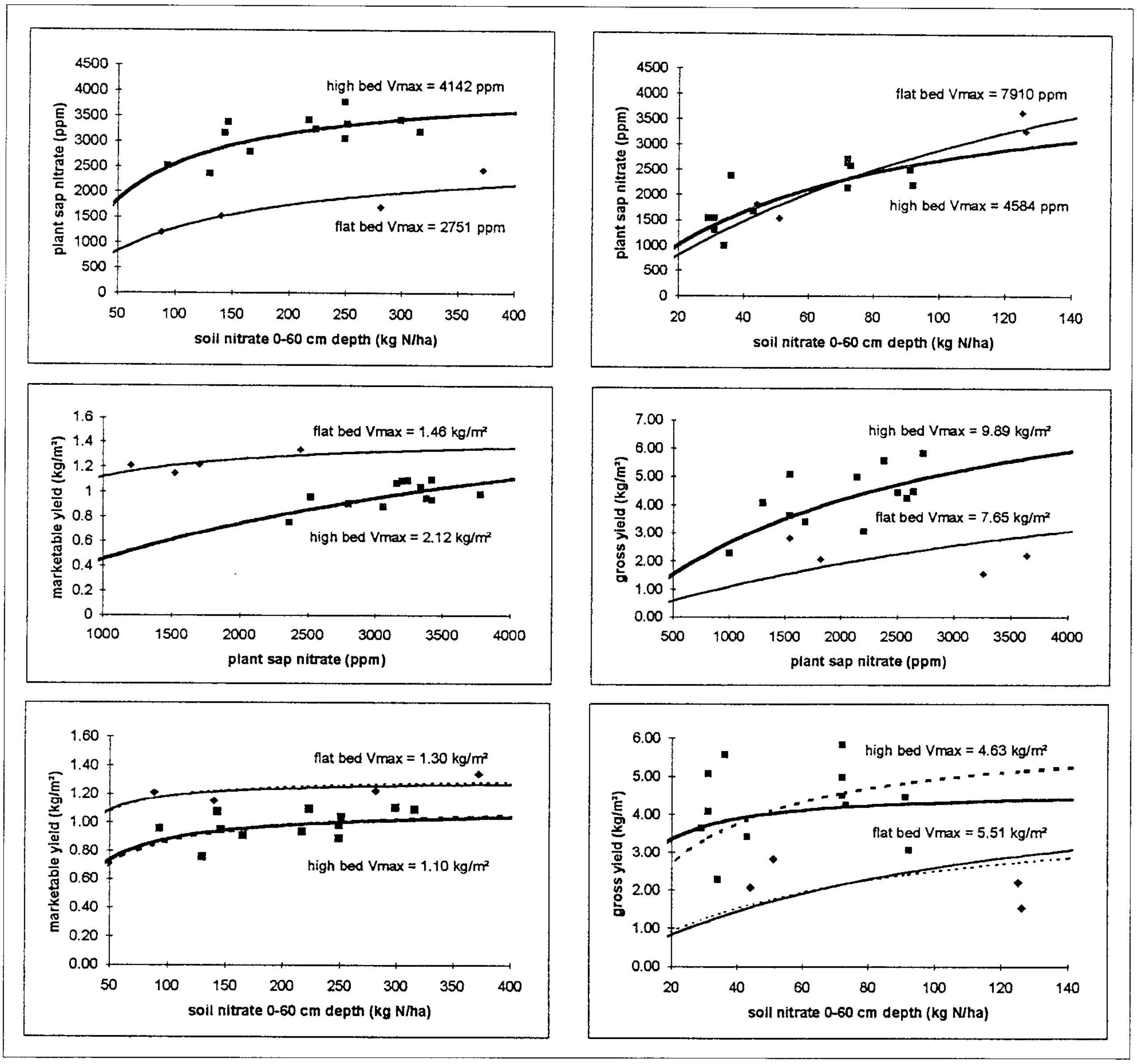


Fig. 3. Hyperbolic regression curves for functional relationships between soil NO_3, plant petiole sap NO_3, and crop yield (left: vegetable soybean; right: Chinese cabbage; thick line: permanent high beds; thin line: flat beds; fad dotted line: regressed function; tine dotted line: estimated function)

Hyperbolische Regressionskurven der funktionalen Relationen zwischen Boden- und Pflanzensaftnitrat sowie Erträgen. (links: Gemüsesojabohne; rechts: Chinakohl; dicke Linie; permanentes Hochbeet; dünne Linie: Flachbeet; dickgepunktete Linie: Regressionsfunktion; feingepunktete Linie: geschätzte Funktion)

NO_3 accumulation. It may be assumed from this that excessive leaching of nitrates during the rainy season is not as important as always thought.

Since soil water content in the top soil averaged less in the high than low beds, plant available N was produced more readily, and less nitrogen for current plant biomass accumulation was lost through immobilization and fixation. Permanent high beds in combination with use of the method was the most resource-efficient option for rainy season summer vegetable production in this experiment.

For the summer season crop of Chinese cabbage the limited NO_3 supply from the soil system most likely restricted yield. Since reduced N fertilization in the N_{min}-treatment did not significantly reduce gross yields compared to the traditional N application rate, both nitrogen application rates were too low given the reduced nitrification potential (= low fertilizer efficiency) of the soils under rainy season conditions.

The differences between cultural systems for reducing this absorbed NO_3 efficiently to amino acids for accumulation of biomass and yield can possibly be attributed to soil - plant water relations, indicating higher water stress (reduced water intake through anaerobic conditions in the root zone) of Chinese cabbage on flat beds and other physiological disorders.

Under presented experimental conditions the integrated analysis of soil N, plant sap N, and crop yield using the hyperbolic approach of the Michaelis-Menten model of saturation kinetics resulted in a sufficiently well-determined mutual functional relationship for vegetable soybean as expressed by the similarities of parameters of regressed and estimated functions for yield=f(soil NO_3-N). Besides highlighting deficiencies in plant nutrition, the significance of petiole sap NO_3 analysis lies also in using the dependency of plant NO_3 = f(soil NO_3), which is usually highly determined to estimate the relationship yield = f(soil NO_3), which is commonly poorly correlated.

For vegetable soybean, the analysis was able to show that no limitations in plant nutrition occurred and that other factors were responsible for the somewhat poorer performance of the crop on permanent high beds. For Chinese cabbage, however, large differences between calculated upper limits for plant NO_3 and measured concentrations revealed sub-optimum nitrogen nutrition of this high-N demanding leafy vegetable during the rainy hot summer season. High soil water contents inhibited nitrification of ammonium fertilizer, even when applied in large doses.

Sincere thanks to BMZ/GTZ for sponsoring this research project.

Summary

Permanent high bed cultivation systems are primarily used to overcome flood damage in vegetable crops cultivated in many lowland peri-urban production zones throughout Asia. Over-doses of nitrogenous fertilizers in intensive tropical and subtropical vegetable production have created concern about impact on environment and product quality, and have led to a demand for better N management practices.

The N_{min}-fertilization method has been tested in a 14-month continuous vegetable cropping sequence with 5 crops in two cultivation systems: flat planting beds and permanent high beds. Permanent high bed cultivation and N_{min}-fertilization method were compared with standard practices to test their potential for more resource-efficient productivity. An integrated study of soil NO_3, plant sap NO_3, and crop yield was undertaken for dry season crops of carrots and vegetable soybean and rainy season crops of Chinese cabbage and chili.

The influence of cultivation system (flat beds versus high beds) on productivity was much more conspicuous than the effect of fertilization regimes. Summer crops of Chinese cabbage and chili pepper in 1993 and Chinese cabbage '94 on high beds out-yielded those on flat beds by 58%, 240%, and 161^0/o for the standard N application rates.

Plant available N concentrations in soil (N_{min}) followed a seasonal pattern of fixation and/or immobilization of ammonium N fertilizer during the rainy summer season, when water saturation inhibited nitrification most of the time. During the winter season this fixed nitrogen reappeared as soils dried out. This was particularly true for the more flood-prone flat beds.

The accelerated mineralization potential during the dry season led to N_{min}-concentrations obviating the need for N fertilization for carrot and vegetable soybean crops. No yield reductions were observed compared to the standard N application rate. Although soil N supply was more limited during the rainy season, only yields of Chinese cabbage during 1994 on high beds were significantly reduced by the N_{min}-method. A total of 360 kg N/ha (42 %) was saved by the N_{min}-method during 14 months and 5 vegetable crops.

The combination of hyperbolic relations of plant NO_3-N as a function of soil nitrate and yield as a function of plant NO_3 resulted in a good estimation of yield =f(soil NO_3) for vegetable soybean. Small differences between measured sap NO_3-levels and calculated upper limits demonstrated that soil N was not a limiting growth factor.

Permanent high bed cultivation in combination with use of the N_{min}-fertilization method was the most resource-efficient combination for out-of-season summer vegetable production.

Zusammenfassung

Bodenverdichtung und stagnierende Nässe verursachen häufig starke Wachstumsschäden bei Gemüsekulturen im tropischen Tiefland während der Regenzeit. Permanente Hochbeete verbessern häufig diese Situation.

In Intensivgemüsekulturen der Tropen und Subtropen sind hohe Stickstoffgaben die Regel. Aber auch hier beginnt man umzudenken zum Schutze der Umwelt und für gesteigerte Produktqualität. Daher wird ein besseres Verständnis für eine optimale Stickstoffdüngung unter diesen besonderen Umweltbedingungen dringend gefordert.

In der vorliegenden Arbeit wurde bei fünf fortlaufenden Gemüsekulturen über 14 Monate auf permanenten Hochbeeten und auf Flachbeeten die bis dahin unbekannte N_{min}-Methode mit der Standardstickstoffdüngung verglichen. Als Maßstäbe dienten Effizienz und Produktivität, da besonders während der regenreichen Sommermonate eine erfolgreiche Gemüseproduktion sehr problematisch ist. In der Studie wurden fortlaufend Nitratwerte im Boden und im frischen Pflanzensaft (mit Merck RQflex) gemessen sowie die Erträge von Gemüsesojabohnen und Karotten während der Trockenzeit und von Chinakohl und Chili-Paprika während der heißen Regenzeit.

Der Einfluß der beiden Kultursysteme (Hoch- und Flachbeet) war sehr viel ausgeprägter als die Steuerung der N-Düngung. Erträge von Chinakohl und Chili-Paprika während der Regenmonate 1993 und von Chinakohl in 1994 waren, auf Hochbeeten gewachsen, um 58 %, 240 % bzw. 161 % höher als auf Flachbeeten bei Standardstickstoffdüngung.

Wassersättigung des Bodens während der Regenzeit verursachte durch Sauerstoffmangel über längere Zeit eine Nitrifikationshemmung. Dadurch wurde der applizierte Ammoniumstickstoff im Boden immobilisiert bzw. fixiert, was ein typisch jahreszeitlich bedingtes Erscheinungsbild der Stickstoffverfügbarkeit und N-Konzentration im Boden (N_{min}) ergab. Während der kühleren Jahreszeit und sobald der Boden austrocknete, wurde dieser Stickstoff pflanzenverfügbar. Dies war besonders in den sehrviel nasseren Flachbeeten zu beobachten.

Das beschleunigte Mineralisationspotential während der Trockenzeit führte zu N_{min}-Konzentrationen, die eine Stickstoffdüngung bei Karotten und Gemüsesojabohnen erübrigte, was sich durch die N_{min}-Testmethode sehr gut zeigte. Keine Ertragsreduzierungen wurden gegenüber der Standardstickstoffdüngung beobachtet. Obwohl die N-Verfügbarkeit während der Regenzeit limitiert war, äußerte sich dies signifikant bei Chinakohlertrag nur 1994 auf Hochbeeten unter N_{min}-Stickstoffsteuerung. Wahrscheinlich wurde dies aber durch sehr starke Auswaschungen während eines Taifuns in der Hauptwachstumszeit verursacht.

Die Kombination der hyperbolischen Relation von Nitrat in der Pflanze zu Bodennitrat und Ertrag als eine Funktion des Pflanzennitrates ergab eine gute Schätzung des Ertrags für Gemüsesojabohne. Kleine Differenzen zwischen gemessenem NO_3 im Pflanzensaft und kalkulierten Höchstmengen demonstrierte, daß Boden-NO_3 keinen begrenzenden Wachstumsfaktor darstellt.

Permanente Hochbeetkulturen in Kombination mit N_{min}-gesteuerterStickstoffdüngung erwiesen sich als das beste Produktionssystem für Gemüsekulturen während der sonst problematischen sommerlichen Regenzeit im tropischen Tiefland.

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