PLANT RESEARCH AND DEVELOPMENT • Volume 49 · 1999
Institute for Scientific Co-operation, Tübingen, Federal Republic of Germany

SOIL MOISTURE, SOIL AND CROP NITROGEN, AND YIELD OF VEGETABLES IN A SEASONALLY WET-DRY TROPICAL LOWLAND

by

VOLKER KLEINHENZ

Asian Vegetable Research and Development Center, Shanhua, Tainan, Taiwan

WILFRIED-HERMANN SCHNITZLER

Institute for Vegetable Science, Technical University Munich

and

DAVID-JAMES MIDMORE

Asian Vegetable Research and Development Center, Shanhua, Tainan, Taiwan

Soil moisture tension, soil and plant sap nitrogen, root length density distribution, and yield were studied in four vegetables year-round during 1994/95 at the Asian Vegetable Research and Development Center (AVRDC) in tropical southern Taiwan. Experimental treatments included two cultivation systems (traditional flat beds and permanent high beds) and N-fertilizer rates (recommended rate and N_{min}-reduced rate). Vegetables were vegetable soybean, Chinese cabbage, chili, and carrot. Nitrification of ammonium applied as ammonium sulfate was studied in different seasons.

Soil nitrate accumulated during the dry season when evaporation exceeded precipitation. This could not be explained by release of nitrogen from the low soil organic matter (< 0.5 % total N) alone. Release of nitrogen from clay-fixed or other soil fractions may be significant in such environments. Therefore, fertilizer rates can be reduced and vegetables with a high capacity to absorb nitrogen should be grown during the dry season to protect nitrate from being lost with the onset of rainfall in the wet season.

Soil moisture was high and soil nitrate low during the wet season. Nitrification of ammonium fertilizer was slower than in the dry season and nitrate disappeared quickly after rainfall. High beds successfully alleviated water stress in vegetables, providing better conditions for greater root mass, effective absorption but less leaching of soil nitrate, and high yields. On more flood-prone flat beds, water stress in vegetables was greater. Root density was low and confined to the topmost soil layer. N-absorption of vegetables on those beds was ineffective, yields remained marginal and more NO_3 was consequently leached below the root zone.

Overall, stresses caused by excessive soil moisture in the wet season and deficient soil moisture in the dry season limited vegetable growth apparently more than limited availability of soil nitrogen.

Intensive year-round vegetable production is a common feature in Asian tropical lowlands, particularly in peri-urban areas around big cities. Climatic conditions in many such areas are dominated by seasonally wet-dry weather with monsoons bringing abundant rainfall during some months of the year. Due to long-term cultivation of rice, soil structure is frequently poor and erratic rainfall can lead to close successions of overdry and overwet soil conditions. In this environment soil moisture must be carefully monitored for successful vegetable production (Kleinhenz et al., 1996a). Besides its direct impact on crops (Kleinhenz et al., 1996b), soil moisture also exerts a strong effect on the availability of nitrogen.

Although nitrate is often associated with pollution of groundwater and potentially harmful concentrations in vegetables, it is the essential nitrogen form for many vegetable species. Roots of dicotyledonous crops are more effective in absorbing NO_3-N than NH_4-N (Scarsbrook, 1965). For some species like Chinese cabbage ammonium nutrition can be harmful or even toxic. Availability of nitrogen to such crops thus depends on the soil nitrate content.

In seasonally wet-dry climates, soil nitrate may be affected by a number of factors. Mineralization of organic soil nitrogen proceeded most rapidly at low soil moisture tensions of 3 to 10 kPa in some soils (Stanford and Epstein, 1974). In flooded soils, the mineralized ammonium nitrogen will accumulate because of anoxic conditions. However under drier upland conditions, NH_4 is usually quickly oxidized to nitrate which can accumulate to substantial levels (Terry and Tate, 1980). Conditions that might adversely affect nitrification include excessive moisture and high temperatures (Justice and Smith, 1962). Other processes limiting availability of soil nitrogen to upland crops include leaching of the highly mobile NO_3^- ion, denitrification of nitrate to N_20 and N_2, immobilization of ammonium-N by microorganisms, fixation of ammonium to clay minerals, and under certain conditions leaching of ammonium.

Although many of the above-mentioned processes have been studied in detail, information on N availability in intensive vegetable production in tropical lowlands is rather limited. The aim of this study is, therefore: (1) to evaluate the impact of a seasonally wet-dry tropical climate on soil moisture, soil N availability, crop N status, root length density distribution, and yield, (2) to determine the relative influence of water stress and nitrogen availability on crop yields, and (3) to estimate potential leaching losses of N in intensive, year-round vegetable production on two different bed heights under two N fertilization regimes.

Materials and methods

Site, systems, and crop management

During 1994/95, intensive year-round vegetable production on the same plot was studied at AVRDC, Shanhua in southern Taiwan (23° N latitude). Weekly sums of evaporation averaged 35.9 mm and weekly sums of precipitation are presented in Fig. 1. Soil at the experimental site was an alluvial sandy loam (< 0.5 % total N, 18 % clay containing illite and vermiculite, 27 % silt, and 55 % sand). Cultivation systems consisted of traditional flat

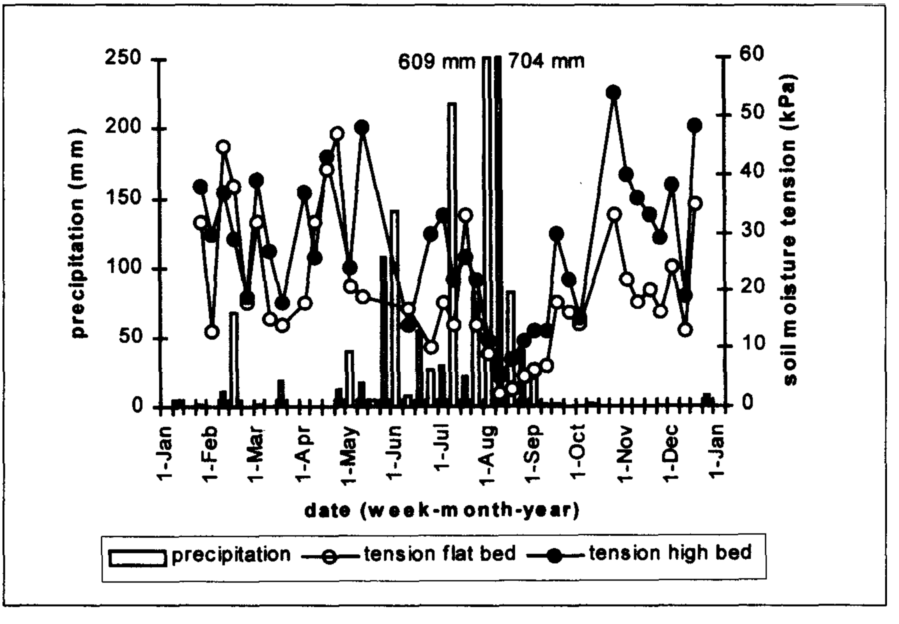

Fig. 1 – *Weekly precipitation and mean weekly soil moisture tension at 15 cm soil depth during 1994in flat and high beds.*

beds (1.5 m wide and 20—25 cm high), which were prepared before sowing or transplanting each crop, and permanent high beds (3.0 m wide and 50 cm high) constructed in spring 1992. Flat beds and high beds were 40 m long, divided into 20-m-long flat-bed plots and 4-m-long high-bed plots, randomized in a complete block design with four replications.

During 1994/95 four vegetable crops, namely vegetable soybean *(Glycine max.* L. Merr; cv. `AGS 292', AVRDC), Chinese cabbage *(Brassica pekinensis* Lour. Rupr.; cv. `ASVEG No. 1', AVRDC), chili *(Capsicum annuum* L.; variety `Hot Beauty', Known You Seed Co.), and carrot *(Daucus carota* L. ssp. *sativus* Hoffm. Arcang.; cv. `Parano', Nunhems) were cultivated with two nitrogen fertilizer rates: (1) the commonly used traditional ('standard') N application rate, and (2) a rate reduced by the amount of mineralized nitrogen before application (N_{min}-reduced method). Fertilizer nitrogen was applied as ammonium sulfate, rototilled into the soil for all basal applications, and applied to the soil surface for all side-dressings. Details of $N_m$in-content and crop N fertilization are presented in Table 1. Vegetable crops were irrigated during dry periods with a pipe irrigation system. Plant protection and other crop management practices followed standard AVRDC recommendations.

Measurement of soil moisture tension and calculation of water stress

Soil moisture tension was measured with vacuum gauge tensiometers installed at 15 cm soil depth within crop rows in a flat bed (one crop row), and two high beds (three crop rows) with two replications. Readings were taken at approximately two-day intervals during the crop cultivation periods when field conditions allowed access. Total water stress was estimated for individual crops by a modified calculation of Taylor's "mean integrated soil moisture tension" (Taylor, 1952) to account for stress caused by overdry and overwet soil conditions according to the equation:

$$T_{pm} = \frac{\sum_{i=0}^{m} (d_{i+1} - d_i)\, ABS\,(T_i - T_{opt})}{\sum_{i=0}^{m} (d_{i+1} - d_i)}$$

where T_{pm} is the mean integrated soil moisture tension, i represents a single time, m represents the total number of tensiometer 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, T_i is the moisture tension at a single time, and T_{opt} is an 'optimum' soil moisture tension, which was approximated for each crop by an iteration procedure.

Table 1 – *Soil N_{min} contents (mean ± standard error) and N -fertilizer application rates used for four vegetable crops cultivated in two cultivation systems during 1994/95*

Crop	Vegetable soybean			Chinese cabbage			Chili			Carrot	
Cultivation period (week-month)	1-Mar to 4-May			4-May to 3-Jul			4-Aug to 4-Dec			2-Jan to 1-Apr	
Year	1994			1994			1994			1995	
Date of application (week-month)	1-Mar	1-Apr	1-May	4-May	2-Jun	4-Jun	3-Jul	4-Aug	2-Nov	2-Jan	4-Mar
N_{min}-content before fertilization											
Flat bed (kg NO_3-N/ha)	43 ± 5.0	120 ± 10.2	51 ± 4.1	22 ± 2.8	32 ± 5.5	21 ± 1.2	16 ± 2.4	52 ± 6.0	23 ± 4.7	18 ± 2.8	52 ± 7.8
High bed (kg NO_3-N/ha)	16 ± 3.9	101 ± 7.2	20 ± 2.0	19 ± 1.6	39 ± 4.4	13 ± 2.0	20 ± 2.9	25 ± 2.5	21 ± 4.9	25 ± 3.5	48 ± 9.4
Fertilizer application rate											
Traditional rate (kg N/ha)	20	20	20	60	30	30	50	50	50	60	60
N_{min}-reduced method (kg N/ha)	0	0	0	20[1]	0	0[1]	30	20	30	40	10

[1]Nm_{in}-calculation included expected N-release from incorporated vegetable soybean residues

Soil nitrogen analysis

Soil nitrogen was measured by sampling cropped soil 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 in four flat and four high beds (standard N application rate and N_{min}-reduced method; two replications). Between sampling and analyzing, samples were stored in a cooler. Extracted 1:2 by volume in 0.8 % KCl water solution, samples were filtered and analyzed for NO_3 and NH_4 using Merck's RQflex reflectometer, Reflectoquant nitrate (5-225 ppm), and Reflectoquant ammonium (0.2-7.0 ppm) analytical test strips. The reflectometer was tested against a range of nitrate standard solutions with satisfactory results. Holden and Scholefield (1995) confirmed the reliability of the test.

Plant nitrogen analysis

The analysis of nitrate concentrations in sap of petioles of recently matured leaves is recognized as a suitable tool for determining nitrogen nutrition status of crops. Petioles were collected from eight newly expanded leaves per plot for vegetable soybean and carrot. Twenty complete leaves per plot were sampled for chili, and five Chinese cabbage midribs per plot. Between sampling and analysis, petioles were stored on ice. Plant sap was expressed with a garlic press and diluted with deionized water to fit the range of the test strips for NO_3-N analysis.

Nitrification of ammonium fertilizer

Ammonium sulfate was applied at a rate of 60 kg N/ha to flat bed and high bed plots (8 and 12 m^2, three replications) kept free of crops and weeds. Application dates were 11 January, 23 March, and 13 June 1995. Both NH_4-N and NO_3-N were measured daily in samples taken from the 0 to 30 cm soil layer until ammonium concentrations were less than 1 ppm. Soil nitrogen content before fertilizer application was subtracted from measured concentrations.

Root length density measurement

Root length was measured in one flat bed and one high bed shortly before final crop harvest using the "gridline intersect method". 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 centimeters was determined by the number of counted root/gridline intersects. 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.

Crop yield determination

Crop yields were recorded for bordered areas from individual rows. Soybean pods were handpicked in one harvest and the fresh weight was recorded. Chili peppers were picked on 1 November, 15 November, 28 November, and 20 December. Chinese cabbage net (marketable) yield was deter-mined as head yield without wrapper leaf. Carrot yield was recorded as root yield without leaf.

Multiple regression of yield on water stress and soil N availability

Values of final mean integrated soil moisture tension, average soil NO_3 content and net yield in three plots were transformed to percentages of their joint mean for each of the four vegetables. The pooled data was analyzed with multiple regression of (relative) net yield on (relative) water stress and (relative) soil NO_3 content.

Results

Soil moisture tension, soil Nmin, and N fertilizer rates in the N_{min}-reduced treatment

The seasonally wet-dry climate was clearly reflected in the distribution of precipitation in 1994 with high rainfall from May through August and virtually no rainfall during the other time of the year (Fig. 1). Those seasonal differences in precipitation were reflected in soil water status with low weekly means of moisture tension during the peak rainy season in August 1994, particularly on flat beds (Fig. 1). Soil nitrate content followed the same trend (Fig. 2). The amount of soil ammonium was usually less than a few kilograms per hectare except immediately after application of ammonium fertilizer.

Since contents of mineralized nitrogen (N_{min}) exceeded crop requirements, no nitrogen was applied to vegetable soybean in the dry season in 1994

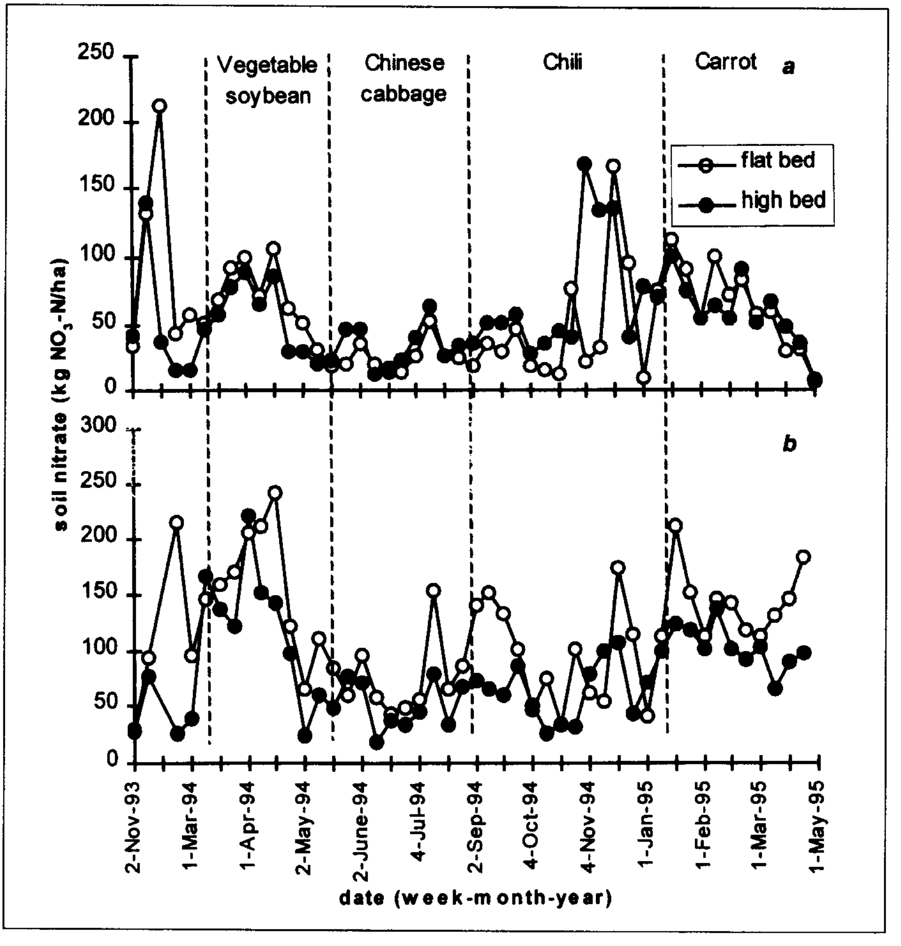

Fig. 2 – Weekly soil contents of available NO_3^- nitrogen at 0 to 30 cm soil depth with 2 N fertilizer application rates; (a) N_{min} reduced method and (b) traditional (standard) rate in two cultivation systems: flat and high beds.

(Table 1). Nevertheless, soil NO_3 peaked at the end of the dry season in late April and early May 1994, with contents partly in excess of 100 kg N/ha (Fig. 2a). With only small amounts of N fertilizer applied during the wet season, soil NO_3 was usually low. When N fertilizer was applied at the standard rate, soil NO_3 contents were generally greater in flat beds, peaking after each application of N fertilizer (Fig. 2b).

Nitrification of ammonium fertilizer

Biological oxidation of ammonium to nitrate follows Michaelis-Menten reaction kinetics (Richter, 1987). Hyperbolic-type decreases in ammonium and increases in soil nitrate were estimated with quadratic regressions in Fig. 3.

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 the dry-season experiment (Fig. 3a). Ammonium was completely oxidized to nitrate in flat and high beds within 12 days after application.

In the second experiment which was conducted in the transition phase from dry to wet season (Fig. 3b), irrigation rates 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 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, ammonium sulfate was applied to a completely saturated soil with soil moisture tension being less then 5 kPa (Fig. 3c). Soil moisture tension increased steadily towards the end of the experiment after a rainfall of 65 mm on day 1. This time, ammonium could be detected in the soil for 3 weeks, indicating that nitrification was delayed.

Interrelationship of N fertilization, soil N content, plant N concentration, and yield

The relationship between (1) nutrient application and crop nutrient uptake and between (2) nutrient uptake and crop yield can be presented in a three-quadrant diagram (van Keulen, 1982). In the present study this was modified to a four-quadrant diagram, to include the relationship between (3) N fertilizer application rate and average soil nitrate content over the cropping period (Figs. 4 and 5). The average plant sap nitrate concentration measured during the cultivation period substituted for total crop nutrient uptake.

There was almost no yield response to N fertilizer during the dry season when vegetable soybean and carrot were grown. This is indicated by flat slopes for both cultivation systems in quadrant d of Figures 4 and 5. During the wet season, N application resulted in higher average soil nitrate contents on flat beds than on high beds (quadrant a). Slopes in quadrant b illustrate that particularly for the chili crop, these contents were not reflected in appreciably greater sap NO_3 concentrations in flat beds. Yields were substantially lower on those beds than on high beds (quadrant c and d).

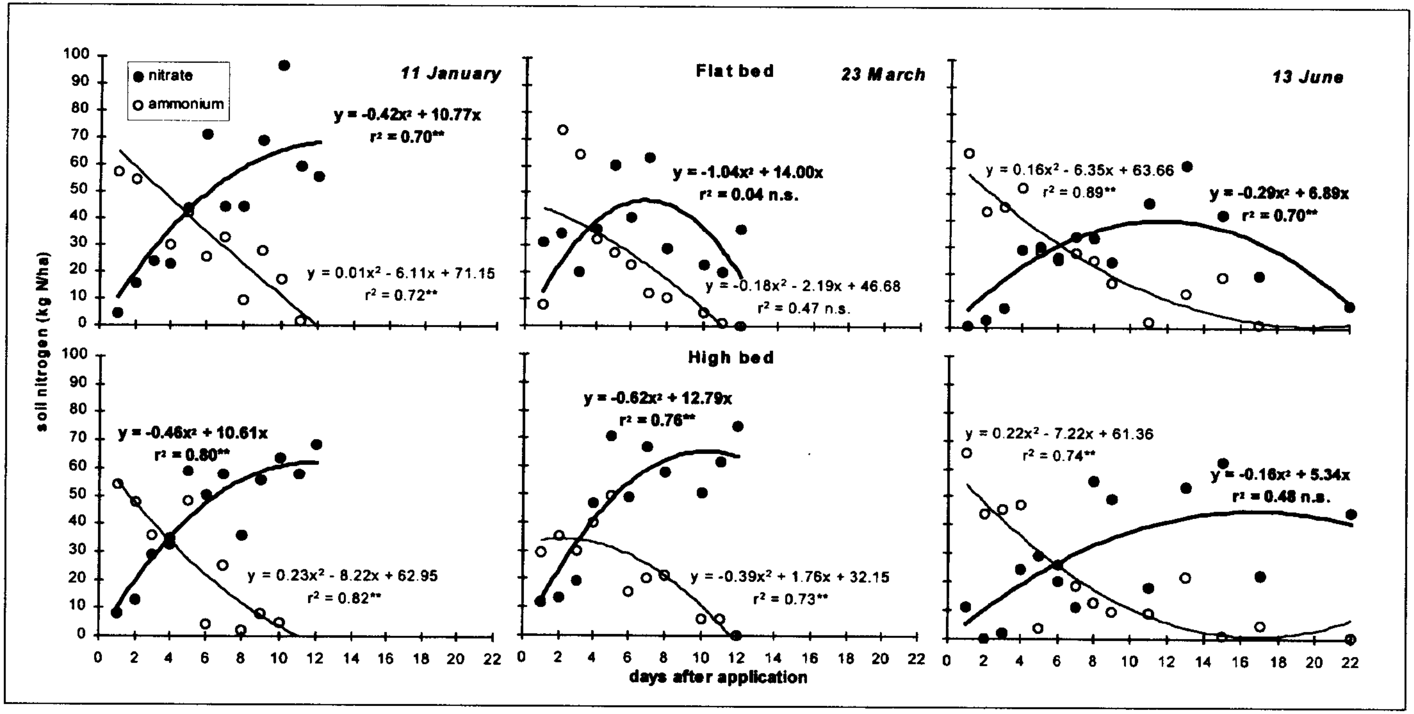

Fig. 3 – Nitrification of ammonium fertilizer (60 kg N/ha as (NH_4) applied on (a) 11 January, (b) 23 March, and (c) 13 June 1995 in two cultivation systems; (top) flat bed and (bottom) high bed as indicated by NH_4 content and NO_3 content in 0 to 30 cm soil depth. Lines represent quadratic trends for (thin line) NH_4-N and (thick line) NO_3-N.

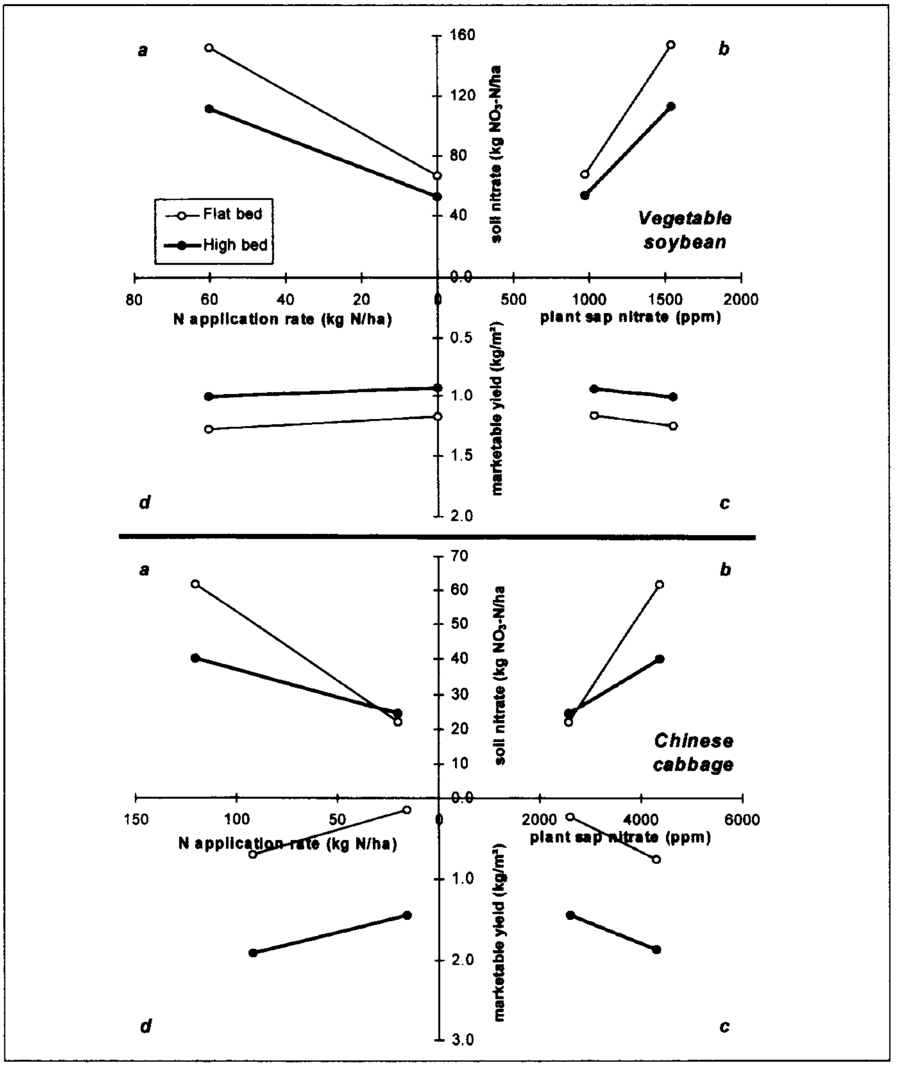

Fig. 4 – *Relationship of (a) N fertilizer application and mean soil nitrate content (0 to 30 cm soil depth), (b) mean soil nitrate content and mean plant sap nitrate concentration, (c) mean plant sap NO_3 concentration and net yield, (d) net yield and N fertilizer application of (top) vegetable soybean from March to May 1994 and (bottom) Chinese cabbage from May to July 1994 in flat and high beds.*

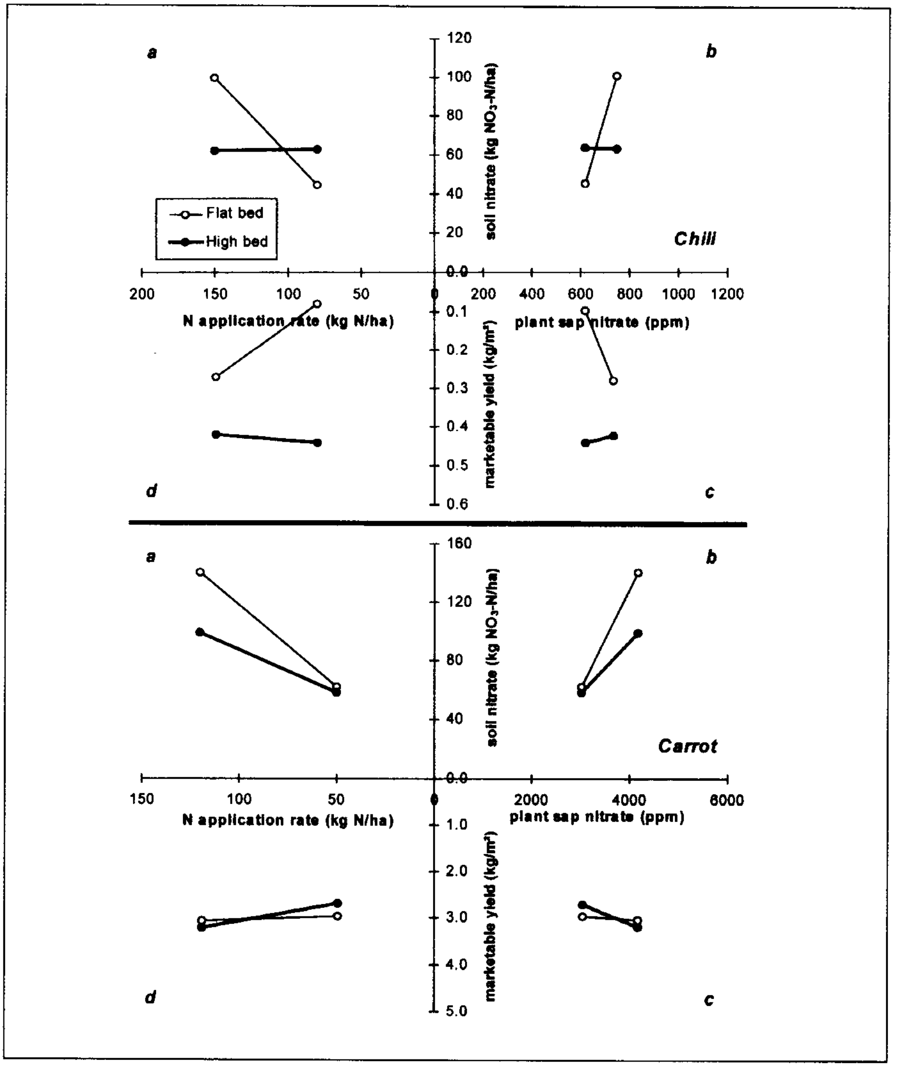

Fig. 5 — Relationship of (a) N fertilizer application and mean soil nitrate content (0 to 30 cm soil depth), (b) mean soil nitrate content and mean plant sap nitrate concentration, (c) mean plant sap NO_3 concentration and net yield, (d) net yield and N fertilizer application of (top) chili from August to July 1994 and (bottom) carrot from January to April 1995 in flat and high beds.

Relative influence of water stress and nitrogen availability on vegetable yields

Mean integrated soil moisture tension (MISMT), averages of soil nitrate contents, and yields were converted to percentages of the mean of three measurements. This allowed comparison across crops (Table 2) by multiple regression. The analysis gave:

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

indicating that water stress significantly limited crop production. There was a positive correlation between vegetable yields and soil nitrate contents but the regression parameter was not significant.

Table 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 (HBI, HB2) for the multiple regression of net yield on water stress and soil N availability*

	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
Mean soil N content ($kg\ NO_3$-N/ha)	80	45	72	66	121	68	109
Net yield (kg/m²)	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
Mean soil N content ($kg\ NO_3$-N/ha)	24	21	21	22	109	22	96
Net yield (kg/m²)	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
Mean soil N content ($kg\ NO_3$-N/ha)	35	62	36	44	80	141	82
Net yield (kg/m²)	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
Mean soil N content ($kg\ NO_3$-N/ha)	53	32	32	39	136	82	82
Net yield (kg/m²)	3.09	2.65	3.10	2.95	105	90	105

Root length density and leaching of soil nitrate

Root density was restricted to the top 50 cm soil depth in both flat and high beds (Table 3). Total root density in that profile was greater in high beds for all vegetables. Fewer roots were found above 20 cm depth, but root elongated more profusely in the 20 to 40 cm soil layer.

Since root density was low beneath 40 cm, soil nitrate content at 30 to 60 cm soil depth indicated potential nitrogen loss through leaching. Nitrate contents were particularly high at the end of the dry season and low during the wet season (Fig. 6 a and b). Amounts of NO_3 that were leached below the root zone were similar for high beds under both rates of N fertilizer application, but potential leaching losses were higher in flat beds when the standard rate was applied.

Discussion

Although only small amounts of fertilizer N were applied in the ^{N}min-treatment, soil nitrate accumulated during the dry season (Fig. 2a). Nitrate accumulation in the dry season was observed in several seasonal wet-dry climates in the tropics by Greenland (1958). Although soil moisture is probably too low for maximum N mineralization, leaching of NO_3 is minimal in this season (Reynolds-Vargas et al., 1994). Nitrate can accumulate in the surface soil through upward movement from subsoils when evaporation exceeds precipitation. Mineralization might have also been accelerated during the dry season through alternate drying and rewetting of the soil during irrigation cycles (McLaren and Peterson, 1965). Although nitrification of ammonium proceeded rapidly and completely in the dry season (Fig. 3a), soil nitrate accumulated to levels that could not be explained by lack of leaching alone. It could not be expected that great amounts of nitrogen would be mineralized from the low pool of organic nitrogen. Although not monitored in this study, release and nitrification of nonexchangeable, clay-fixed ammonium may be important in this environment. Soils contained certain amounts of the ammonium-fixing clays illite and vermiculite, particularly in the subsoil. Considerable amounts of nitrogen can be present in this form and may play a significant role in N nutrition of crops (Keerthisinge, 1984).

Soil nitrate peaked before the onset of rainfall in the wet season (Fig. 2 and 6). This has consequences for crop production in this environment. Mineralization of soil nitrogen in the dry season 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). This nitrogen quickly declined at the

Table 3 — *Distribution of root length density (mean ± standard error; flat bed: n = 6, high bed: n = 14) of four vegetables cultivated on flat beds and high beds during 1994/95*

Depth (cm)	Vegetable soybean		Chinese cabbage		Chili		Carrot	
	Flat bed (cm/cm^3)	Highbed	Flat bed (cm/cm^3)	High bed	Flat bed (cm/cm^3)	High bed	Flat bed (cm/cm^3)	High bed
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

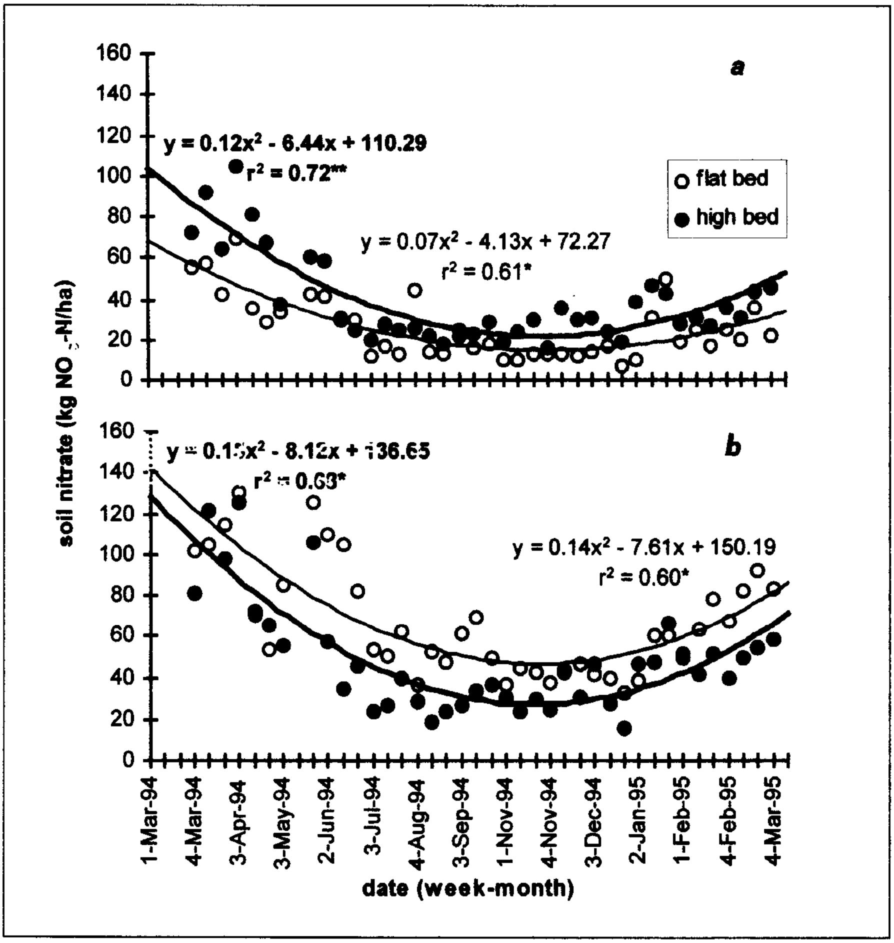

Fig. 6 – *Weekly soil contents of available NO_3-nitrogen at 30 to 60-cm soil depth with 2 N fertilizer application rates; (a) N_{min} reduced method and (b) traditional (standard) rate; in AVRDC/ Taiwan from 1994 to 1995 in flat and high beds. Lines represent quadratic trends for (thin line) flat beds and (thick line) high beds.*

onset of rainfall in the wet season. This loss during transition from dry to rainy season can be explained by leaching and denitrification, processes which harm the environment (Kleinhenz et al., 1997). The potential loss of soil nitrate is greatest under the cropping pattern winter vegetables — spring rice crop which is common in lowland Taiwan (Chiu, 1987) and other similar climates. Cropping patterns of upland crops followed by paddy rice virtually eliminate percolation of nitrate to the groundwater, but accelerate denitrification of NO_3 (Terry and Tate, 1980). Buresh et al. (1993) described the important role of green manure between a dry season and a wet season rice crop. The catch crop may absorb soil nitrate to resist leaching, and cycle this N back to the soil N pool so that it can be used by the following rice crop. In highly intensive vegetable production, it may be recommended to incorporate a vegetable with high N absorption capacity (e.g. sweet corn) as a cropping component to remove high soil nitrate contents before the onset of the rainy season.

High fertilizer rates on flat beds were reflected in contents of soil inorganic nitrogen, which peaked after each application. However, greater soil nitrate did not appreciably raise plant sap NO_3 concentrations, particularly in the rainy season. Under high soil moisture, i.e. low water tension, root systems of vegetables accumulated close to the soil surface (Kleinhenz et al., 1996b). Deeper penetrating roots were confined to taproots with less branches and root hairs. This reduced total rootmass on flat beds, so that available soil nitrogen could not be effectively absorbed by crops. This brought about poor biomass production in vegetables and hence low yields. The nitrogen that was not absorbed was easily leached out of the root zone.

Wesseling (1974) stated that the efficiency of applied N fertilizer depends largely on drainage conditions. On high beds, total root mass was greater and root systems elongated to greater depth than on flat beds. Roots were rich in long, slender and soft mainroots with a lot of branches and roothairs. Therefore, available soil nitrogen was efficiently absorbed by vegetables and biomass production was kept high throughout the season. Consequently, the higher application rate of fertilizer N did not result in greater potential leaching losses (Fig. 6).

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 only secondary when soil water stress occurred.

Note

We thank the German Federal Ministry of Economic Cooperation (BMZ) for funding and the Asian Vegetable Research and Development Center for its support in the implementation of this project.

REFERENCES

AVRDC (1995): AVRDC 1994 Progress Report. Asian Vegetable Research and Development Center, Shanhua, Tainan, Taiwan.

BURESH, R. J. – T. T. CHUA – E. G. CASTILLO – S. P. LIBOON and D. P. GARRITY (1993): Fallow and Sesbania effects on soil nitrogen dynamics in lowland rice-based cropping systems. Agron. J. 85, 316—321.

CHIU, C. C. (1987): Evolution of farming systems in Taiwan. ASPAC Extension Bulletin 265. Food and Fertilizer Technology Center, Taipei, Taiwan.

GREENLAND, D. J. (1958): Nitrate fluctuations in tropical soils. J. Agric. Sci. 50, 82—92.

HOLDEN, N. M. and D. SCHOLEFIELD (1995): Paper test-strips for rapid determination of nitrate tracer. Corn. Soil Sci. Plant Anal. 26, 1885—1894.

ISFAN, D. (1984): Corn yield variation as related to soil water fluctuation and nitrogen N-fertilizer. II. Soil water-nitrogen-yield relationships. Com. Soil Sci. Plant Anal. 15, 1163—1174.

JUSTICE, J. K. and R. L. SMITH (1962): Nitrification of ammonium sulfate in a calcareous soil as influenced by combinations of moisture, temperature, and levels of added nitrogen. Soil Sci. Soc. Am. Proc. 26, 246—250.

KEERTHISINGHE, G. – K. MENGEL and S. K. DEDATTA (1984): The release of nonexchangeable ammonium (^{15}N labelled) in wetland rice soils. Soil Sci. Soc. Am. J. 48, 291—294.

VAN KEULEN, H. (1982): Graphical analysis of annual crop response to fertiliser application. Agric. Systems 9, 113—126.

KLEINHENZ, V. – W. H. SCHNITZLER and D. J. MIDMORE (1996a): Diversification and transformation of Asian paddy rice fields to upland vegetable production. Plant Research and Development 43, 81—94.

KLEINHENZ, V. – W. H. SCHNITZLER and D. J. MIDMORE (1996b): Permanent high-bed technology to improve intensive vegetable production in tropical lowlands — Effect on water stress, root distribution, and yield. Hort. Sci. 43, 81—94.

KLEINHENZ, V. – W. H. SCHNITZLER and D. J. MIDMORE (1997): Consideration of the soil $N_{m}i_{n}$ content in N fertilization of vegetables in intensive, year round production in a tropical, rice-based lowland. Gartenbauwissenschaft 62, 137—144.

MCLAREN, A. D. and G. H. PETERSON (1965): Physical chemistry and biological chemistry of clay mineral-organic nitrogen complexes. In: W. V. BARTHOLOMEW and F. E. CLARK (eds.): Soil Nitrogen. American Society of Agronomy, Madison, Wisconsin, 261—286.

REYNOLDS-VARGAS, J. S. – D. D. RICHTER and E. BORNEMISZA, (1994): Environmental impacts of nitrification and nitrate adsorption in fertilized andisols in the Valle Central of Costa Rica. Soil Sci. 157, 289—299.

RICHTER, J. (1987): The Soil as a Reactor. Catena Verlag, Cremlingen.

SCARSBROOK, C. E. (1965): Nitrogen availability. In: W. V. BARTHOLOMEW and F. E. CLARK (eds.): Soil Nitrogen. American Society of Agronomy, Madison, Wisconsin, 486—501.

STANFORD, G. and E. EPSTEIN (1974): Nitrogen mineralization — water relations in soils. Soil Sci. Soc. Am. Proc. 38, 103—107.

TAYLOR, S. A. (1952): Estimating the integrated soil moisture tension in the root zone of growing crops. Soil Sci. 73, 331-339.

TERRY, R. E. and R. L. TATE (1980): Effect of flooding on microbial activities in organic soils: nitrogen transformations. Soil Sci. 129, 88-91.

WESSELING, J. (1974): Crop growth and wet soils. In: J. VAN SCHILFGAARDE (ed.): Drainage for Agriculture. American Society of Agronomy, Madison,Wisconsin, 7-38.

Author's address: Dr. V. Kleinhenz, Central Queensland University, Plant Sciences Group, Rockhampton, Qld 4702, Australia.