Crop and N Management to Improve Environmentally Sound Vegetable Production in Tropical Lowlands

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Abstract

The crop-management technology of permanent high beds and the N-management technology 'N_{min}-reduced method' were compared with standard practices (flat beds and standard N rates) for their potential to increase vegetable production and prevent environmental pollution with nitrogen in a year-round sequence of four vegetable species during 1994/95 at the Asian Vegetable Research and Development Center (AVRDC) in the tropical lowland of southern Taiwan. During the rainy season, contents of plant-available soil nitrogen were low, but soil nitrate accumulated during the dry season, partly obviating the need for fertilising vegetables in this season. 62 percent nitrogen was saved by reducing the standard N rates by the amount of soil nitrate before fertiliser application. No yield differences were found between the standard N rate and the N_{min}-reduced rate on flat beds. However, biomass production and yields remained low. Flat beds were more flood-prone during the rainy season. Root systems of vegetables on those beds were restricted to the uppermost soil layer. Both factors limited the ability of vegetables to efficiently absorb available soil nitrogen. Consequently, the unused extra nitrogen of the standard N rate leached below the root-zone. Permanent high beds successfully alleviated the negative impacts of overwet soil conditions during the tropical rainy season. Rootmass of vegetables was greater and more roots stretched below 20-cm soil depth. Available soil nitrogen was effectively absorbed and thereby leaching of nitrate prevented. The standard-N rate was completely absorbed, but the N_{min}-reduced rate could not maintain maximum yields of vegetables. It appears, that crop management technologies which improve growth and productivity of vegetables in tropical lowlands may have a more significant impact on reducing environmental pollution with nitrogen than N management itself.

1. Introduction

Future increase in food production is an undisputed objective of the future. The supply of the people with carbohydrates has improved world-wide in the last decades, but numerous micro-nutrients are largely deficient, particularly in Africa and South Asia [1]. Vegetables are a major source of essential micro-nutrients [2] of which increased consumption has been highlighted as a priority social development objective in some tropical countries [3]. Not only in Asia, a swelling majority of the population lives in the tropical lowlands. Therefore, increasing vegetable production in the lowland tropics has recently been proclaimed as a major route to provide a larger amount of food and nutritious substances for the large numbers of people living in this agri-ecological zone [4].

Hand in hand with crop breeding programs, crop management technologies have shown their potential to increase vegetable production in tropical lowlands. This is particularly true for the difficult rainy season when market supply is largely deficient and, therefore, vegetable consumption of the people is low [5]. Many of these techniques have been developed [6] and one of them is the construction of permanent high beds which are primarily adopted to relax production constraints of excess soil water during heavy rainfall periods [7]. Such cultivation systems are used in some localised areas in south-east Asia.

Although information is limited, there is an indication that application rates of inorganic nitrogen in tropical vegetable production are alarming high and exceed recommendced rates oftentimes manifold. In Taiwan, farmers usually apply as much as ten times more inorganic nitrogen to vegetable soybean than recommended [9]. For pea, cabbage, eggplant, and Chinese chive, farmers frequently use nitrogen at rates up to five times greater than the recommended input [10]. Besides the detrimental effects of this over-doses on the properties of soils [10], leaching of nitrates to the groundwater [11] is of great concern. Appropriate N-management techniques may be useful strategies for maintaining maximum vegetable yields and thereby reducing leaching losses of nitrogen [12]. For this, the 'N_{min}-method' [13] has been introduced to Central Europe. Everaarts [14] proposed a simplified N_{min}-method for production conditions where standards for controlled N-fertilisation are lacking. In tropical vegetable production, a 'N_{min}-reduced method' was tested following Everaarts 'suggestions [15]

The aim of this paper is to evaluate the impacts of (1) the crop management technique of permanent high beds and (2) the N-management technique 'N_{min}-reduced method' on : (a) soil water, (b) root systems of vegetables, (c) soil nitrogen in and below the root zones of vegetables, (d) vegetable yields, and (e) fertiliser-use efficiency. The technologies were compared to standard practices in a continuous, year-round vegetable sequence of four species during 1994/95 at the Asian Vegetable Research and Development Center (AVRDC) in the tropical lowland environment of southern Taiwan.

2. Materials and Methods

Site

The experiment was conducted at the experimental farm of AVRDC, Shanhua in the alluvial lowland plain of southern Taiwan at 23° latitude and an elevation of eight meters above sea level. Mean daily air temperature, mean daily soil temperature, and mean daily evaporation for 1994/95 were 25.1° C, 14.4° C, and 4.9 mm. Soil at the experimental site was an alluvial sandy loam (<0.5 % total N, 18% clay, 27% silt, 55% sand).

Crop management techniques

As the standard crop management treatment, traditional flat beds (20-25 cm high, 1.5 m wide, width of furrows : 40 cm) were prepared before sowing or transplanting each crop. As the improved crop management treatment, permanent high beds (50 cm high, 3 m wide) were constructed between 2.0-m wide furrows before the onset of the experiment in 1993 (Fig.1). Flat and high beds were 40 m long, divided into 20-m-long flat-bed plots and 4-m-long high-bed plots, randomised in a complete block design with four replications. The experiment included some other treatments which will not be mentioned here. During 1994/95 four vegetable crops : 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.; cv. 'Hot Beauty', Known You Seed Co.), and carrot (Daucus carota L. ssp. sativus Hoffm. Arcang.; cv. 'Parano', Nunhems) were cultivated.

Vegetable soybean and carrot were directly sown during the dry season, and Chinese cabbage and chili transplanted duting the rainy season. Vegetable crops were irrigated overhead with perforated pipes. Plant protection followed current AVRDC recommendations for the various crops. Marketable yields were recorded from bordered areas (flat bed : 27 m^{-2}, high bed : 9 m^{-2}) in individual plots.

N-management techniques

Standard rates of fertilisers (N, P, and K) for the vegetable species followed AVRDC recommendations. For measuring N_{min}, soil samples were taken from flat beds and high beds where the N_{min}-reduced rate was applied (four replications). The N application rate in the N_{min}-reduced treatment was calculated by subtracting the measured amount of soil NO_3 before fertiliser application from the standard N rate. This amount was the mean of NO_3 at 0 to 30-cm soil depth. Except soon after fertiliser application, soil ammonium was in a range of a few kilograms per hectare and was, therefore, not considered for calculating the N_{min}-reduced rate. Nitrogen was applied as ammonium sulphate, phosphorus as calcium superphosphate, and potassium as potassium chloride. Fertilisers were mixed and tilled into the soil for basal applications and applied to the soil surface for side dressings.

Soil moisture tension

Soil moisture tension was measured in the four vegetable crops from February 1994 until May 1995. Vacuum gauge tensiometers were installed with two replications in crop rows in two flat beds (one row, n=4) and in two high beds (three rows, n=12; Fig.1). Installation depth was 15 cm. Readings were taken at approximately two-day intervals from transplanting or seedling emergence until harvest of each crop.

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 centre of beds with two replications (Flat bed: n=6, high bed: n=14). 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 centimetre was determined using the 'gridline intersect method' [16] by counting the number of root/gridline intersects [17]. 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.

Soil nitrogen

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 Novenber 1993 until May 1995. Samples were taken with four replications in flat beds and high beds where the standard N rate and the N_{min}-reduced rate was applied. Soil was extracted for two minutes in 0.8% KC1 aqueous solution by 1:2 in volume while stirred by an electric mixer. Samples were filtered and analysed for NO_3 using Merck's RQflex reflectometer with Reflectoquant nitrate (5 to 225 ppm) analytical test strips. Holden and Scholefield [18] confirmed the reliability of the test. All readings were calculated from concentration (ppm) to amount (kg ha^{-1})

Data analysis

Yield data were analysed in individual cultivation systems (flat beds and high beds) with a one-factorial ANOVA (four replications). Means of levels of 'fertiliser rate' (standard rate vs. N_{min}-reduced rate) were separated with the LSD-test. Overall comparison of cultivation systems (flat beds vs. high beds) and fertiliser rates (standard rate vs. N_{min}-reduced rate) was performed with orthogonal contrasts. ANOVA, regressions, and standard errors were calculated with SAS [19].

3. Results

Soil moisture tension

Vegetable soybean and carrot in the dry seasons 1994/95 were mainly affected by stresses resulting from overdry soil conditions which were more pronounced on high beds. Chinese cabbage was affected by both, excessive and deficient soil moisture [20]. From end of July until mid of August torrential rainfalls partly exceeded 300 mm day^{-1} (Fig.2). This resulted in flooded soil conditions soon after transplanting chili. Soil moisture in flat beds approached lower tensions than in high beds until mid of September (Fig.2). After the onset of the dry season in autumn, the course of soil moisture changed to a periodic pattern of drying and re-wetting typical for fully irrigated field conditions. During this period, soil moisture tension in flat beds averaged lower values with smaller amplitude than in high beds in which higher averages and greater deviations were recorded.

Root-length-density distribution

Root-length density of all vegetable species was typically restricted to the top 50-cm soil depth in flat and in high beds [20]. For chili during the rainy season, root density was greater above 20-cm depth in flat beds, but less roots elongated below this depth (Fig.3). Roots were dark, thick, crooked, and without branches and root hairs. The average of root density in the whole profile was greater in high beds (0.49 cm cm^{-3}) than in flat beds (0.33 cm cm^{-3}). Although roots did not stretch out much deeper into the soil, fewer roots were found above 20-cm depth and 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.

Soil N_{min}-and N-application rates

A total of 450 kg ha^{-1} nitrogen was applied to the four vegetable crops during the 13-month cropping sequence using the standard rates of N fertiliser. Soil N_{min}-contents were high during the dry season in 1994 when vegetable soybean was cultivated. Therefore, no N fertiliser was applied to this crop (Table 1). 280 kg ha^{-1} N or 62 percent were saved by applying the N_{min}-reduced method.

Soil nitrogen

Root density was low below 40-cm soil depth. 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. 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 seasons and low during the rainy season (Figs 4 cnd 5). Application of the standard N rate significantly increased soil nitrate at 0 to 30-cm depth on flat beds particularly during the rainy season, e.g. when the basal application and the first side dressing was applied to chili (Fig.4). However, nitrate contents decreased in a few weeks. On high beds, application of N fertiliser was not much reflected in soil nitrate in th root zone. Soil nitrate peaked at the end of the dry season in April 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.

Compared to the standard N rates, adoption of the N_{min}-reduced method lowered soil nitrate contents in and below the root zone of vegetables throughout the season (Fig.5). Although no N fertilisers were applied during the dry season early 1994, soil nitrate accumulated until mid of April. 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.

Vegetable yields

Except carrot, high beds outyielded flat beds in all other crops (Table 2). Differences in productivity were not so great during the dry season:compared to standard flat beds, yields on high beds were 24 and 6 percent greatrer for vegetable soybean and carrot (standard N rate). However, high beds clearly improved vegetable yields during the rainy season:yields of Chinese cabbage and chili were 44 and 64 percent better on high beds when the standard N rate was applied. There were no significant yield differences between the two fertiliser treatments on flat beds, i.e. application rates of N fertiliser could be reduced by 62 percent without negatively affecting yields on those beds. Reductions in N fertiliser following tne N_{min}-reduced method decreased vegetable yields on high beds: all differences were signficant at the five-percent level (Talbe 2). Overall, reducing N rates during the dry seasons had a less detrimental effect on productivity of vegetables than during the rainy season as indicated by orthogonal contrasts.

Fertiliser-use efficiency

Values of fertiliser-use efficiency (FUE) presented in Talbe 3 cannot be compared across vegetable species. For the standard N-rate, efficiencyt of N fertiliser was greater on high beds for all vegetables. However, when the lower N_{min}-reduced rates were applied, FUE was less on high beds than on flat beds for Chinese cabbage and carrot, and only slightly better for chili. Reducing N application on flat beds greatly improved FUE on those beds. On high beds, increases in FUE were not as conspicuous as on flat beds.

4. Discussion

Following the heavy rainfall period from end of July until mid of August, soil moisture tension was always greater on high beds than on flat beds (Fig.2). High beds improved hydraulic conditions of soil under wet conditions. In tropical lowlands, water tables are frequently close to the surface during the rainy season. After heavy rainfall, the soil above becomes rapidly saturated and vertical infiltration diminishes as the gradient in moisture-potential between the upper and the lower soil layer approaches zero tension [21]. On flat planting beds, excessive soil water can then neither drain downwards nor into the shallow furrows which are repidly filled with water. The deep furrows between high beds have much more capacity to drain water. Excessive soil water flows along a horizontal hydraulic gradient and can be removed into the ditches [20]. However, better drainage makes high beds more drought prone during the dry season. From begin of November until end of December, soil moisture tension reached higher absolute tension with greater amplitudes on high beds, stressing the need for a close monitoring of soil water with efficient irrigation systems on those beds.

When cultivated with irrigation and fertilisation, small root systems of vegetables may be sufficient for absorption of water and nutrients [22]. Greater root growth under such conditions may only indicate partitioning of greater energy to the root system and not an increase in water and nutrient uptake [23]. In more flood-prone flat beds, root systems of vegetables were typically restricted to the uppermost soil layer during the rainy season (chili, Fig.3). Flooding may lead to the death of deeper roots and often the proliferation of adventitious and surface ones. This can make them more sensitive to subsequent drought [24]. Yields of rainy-reason chili on flat beds were significantly 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.

Even with the reduced rates of N fertiliser, soil nitrate accumulated during the dry season (Figs 4 and 5). Greenland [25] observed a similar process in several tropical climates with distinct dry and rainy seasons. Reynolds-Vargas et al. [26] attributed this to minimal leaching of $NO3$. 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 [27]. In the tropics, soil temperatures are greater during the dry season and favour mineralization of nitrogen [28]. However, soil nitrate accumulated to levels that cannot be explained by lack of leaching alone, since significant mineralization of N from the low content of soil organic matter (<0.5 percent total N) could not be expected. Release and subsequent nitrification of non-exchangeable, clay-fixed ammonium [29] may have played an important role. Accumulation of soil nitrate during the dry season should have significant consequences for crop production in tropical lowlands. The plant-available nitrogen can at least partially meet requirements of vegetable crops so that additional N-fertiliser applications should be reduced. This finding can also explain the sometimes low recovery of fertiliser-N in this season [5]. When the amount of native soil nitorgen is sufficient for the N-needs of vegetables, additional N from fertilisers will not be absorbed. Nitrate accumulated and peaked just before the onset of the rainy season in April. This nitrate was quickly lost at the onset of rainfall. Leaching and denitrification during the transition from dry to rainy season are known to harm the environment [5]. Buresh et al. [30] discussed the role of green manure during this period in immobilishing mineralised nitrogen to resist leaching, and cycling this nitrogen back to summer crops when N is more limited. A crop species with high N-absorption capacity may be recommended for intensive, year-round vegetable production.

On flat beds, the N_{min}-reduced fertiliser rate was sufficient to maintain maximun yields (Table 2). The nitrogen was rapidly and completely absorbed by vegetables since application did not much increase soil nitrate in the root zone (0 to 30-cm soil depth, Fig.5). However, when the standard N rate was applied, soil nitrate peaked shortly and decreased in a few weeks, particularly during the rainy season (Fig.4). Biomass production and yields were not improved by applying the greater N rate. It can be concluded that the extra nitrogen could not be absorbed by vegetables on flat beds. Besides the detrimental impact of excessive soil water conditions on the active processes of the root system [22], the small total rootmass and its' accumulation to the soil surface triggered the low ability of vegetables on flat beds to effectively absorb available soil nitrogen. Consequently, the unused nitrogen leached below the root zone. Compared to the N_{min}-reduced fertiliser rate, soil nitrate at 30 to 60-cm soil depth was much greater when the standard N rate was applied.

On high beds, year-round productivity of vegetables was significantly greater than on flat beds (Table 2). Reductions in N fertiliser significantly reduced this productivity. At both standard and reduced N rate, the nitrogen doses were rapidly and completely absorbed by vegetables. Neither the standard N rate nor the N_{min}-reduced rate increased soil nitrate in the root zone of vegetables (Figs 4 and 5) as it was observed for flat beds. Since the extra nitrogen was taken up by vegetables, leaching of nitrate to 30 to 60-cm soil depth was not greater than when the lower N_{min}-reduced rate was applied. Total rootmass was higher and more roots elongated to the soil layer below 20-cm depth. Less proneness to soil flooding and better development and distribution of root systems guaranteed a greater capacity of vegtables on high beds to absorb available soil nitrogen.

Fertiliser-use efficiency was greater on high beds when the standard N rate was applied, but less or equal to flat beds with the N_{min}-reduced rate. With adoption of the N_{min}-reduced method, fertiliser-use efficiency increased much more on flat beds (Talbe 3). This can be attributed to the limited ability of vegetables on flat beds to absorb the extra nitrogen of the standard rate: since the N_{min}-rate was sufficient for maximum biomass production, this nitrogen was used more efficiently than the greater N rate of which most of the extra nitrogen was released unused into the environment. The better crop environment provided by high beds increased the capacity of vegetables to absorb soil nitrogen and produce more biomass and yield. Therefore, the standard N rate was used more efficiently on high beds than on flat beds (Table 3). Since yields were significantly reduced, saving of N fertiliser by the N_{min}-reduced method did not increase fertiliser-use efficiency as much as on flat beds.

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. The crop-management technology of permanent high beds improved productivity of vegetables, and thereby reduced pollution of the environment with nitrogen. Only on flat beds, the Nmin-reduced method decreased leaching of nitrate, but yields of vegetables on those beds were significantly lower than on high beds. By increasing vegetable production with crop management technologies, the efficiency of use of external inputs (fertilisers) can be improved, and thereby pollution of the environment prevented.

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5. References

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Table 1. Soil N_{min} contents in the N_{min}-reduced treatment (0 to 30-cm depth) and N-fertilizer schedules of vegetables cultivated with two N-fertilizer rates in two cultivation systems at AVRDC in 1994/95

Vegetable	Vegetable soybean			Chinese cabbage		
Cultivation period (week-month)	1-Mar to 4-May 1994			4-May to 3-Jul 1994		
Date of application (week-month)	1-Mar	1-Apr	1-May	4-May	2-Jun	4-Jun
N_{min}-content before fertilization						
Flat bed (kg NO_3-N ha^{-1})	43	120	51	22	32	21
High bed (kg NO_3-N ha^{-1})	16	101	20	19	39	13
Mean	30	111	36	21	36	17
Fertilizer application rate						
Standard rate (kg N ha^{-1})	20	20	20	60	30	30
N_{min}-reduced rate (kg N ha^{-1})	0	0	0	40	0	10

Vegetable	Chili			Carrot		
Cultivation period (week-month)	3-Jul to 4-Dec 1994			2-Jan to 1-Apr 1995		
Date of application (week-month)	3-Jul	4-Aug	2-Nov	2-Jan	4-Mar	
N_{min}-content before fertilization						
Flat bed (kg NO_3-N ha^{-1})	16	52	23	18	52	18
High bed (kg NO_3-N ha^{-1})	20	25	21	25	48	25
Mean	18	39	22	22	50	22
Fertilizer application rate						
Standard rate (kg N ha^{-1})	50	50	50	60	60	60
N_{min}-reduced rate (kg N ha^{-1})	30	10	30	40	10	40

Table 2. Marketable yield of vegetables as influenced by cultivation systems (flat bed, high bed) and N-fertilizer rates (standard rate, N_{min}-reduced rate) at AVRDC in 1994/95[a]

Vegetable	Vegetable soybean	Chinese cabbage	Chili	Carrot
Analysis of variance				
Flat bed	0.89 a	1.49 a	0.22 a	3.06 a
Standard rate (kg m^{-2})	0.88 a	1.37 a	0.20 a	3.00 a
N_{min}-reduced rate (kg m^{-2})	0.89	1.43	0.21	3.03
Mean				
High bed				
Standard rate (kg m^{-2})	1.10 a	1.99 a	0.36 a	3.24 a
N_{min}-reduced rate (kg m^{-2})	1.05 b	1.32 b	0.29 b	2.99 b
Mean	1.13	1.66	0.33	3.12
Orthogonal contrast (P-value)				
Flat bed vs. high bed	< 0.01	< 0.01	< 0.01	0.13
Standard rate vs. N_{min}-reduced rate	0.06	< 0.01	< 0.01	0.39

[a] Means in each column followed by the same letter are not significantly different ($P = 0.05$)

Table 3 Fertilizer-use efficiency (FUE) in production of vegetables as influenced by cultivation systems (flat bed, high bed) and N-fertilizer rates (standard rate, N_{min}-reduced rate), and change in fertilizer-use efficiency by applying the N_{min}-reduced rate at AVRDC in 1994/95

	Standard rate			N_{min}-reduced rate			Change
	Yield ($kg\ m^{-2}$)	N rate ($kg\ N\ ha^{-1}$)	FUE[a] ( )	Yield ($kg\ m^{-2}$)	N rate ($kg\ N\ ha^{-1}$)	FUE ( )	FUE (%)
<u>Flat bed</u>							
Vegetable soybean	0.89	60	1.48	0.88	0	--	--
Chinese cabbage	1.49	120	1.24	1.37	50	2.74	+121
Chili	0.22	150	0.15	0.20	70	0.29	+93
Carrot	3.06	120	2.55	3.00	50	6.00	+135
<u>Flat bed</u>							
Vegetable soybean	1.10	60	1.83	1.05	0	--	--
Chinese cabbage	1.99	120	1.66	1.32	50	2.64	+59
Chili	0.36	150	0.41	0.29	70	0.42	+75
Carrot	3.24	120	2.70	2.99	50	5.98	+122

[a]Fertilizer-use efficiency = (yield $N\text{-rate}^{-1}$)100

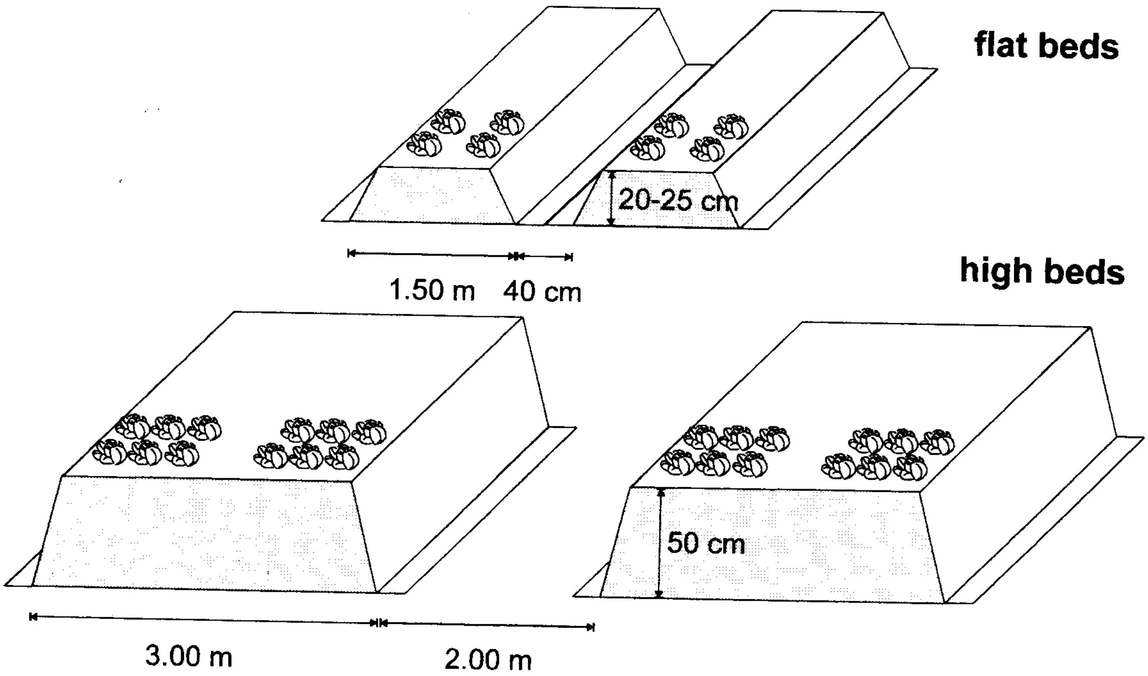

Figure 1 Layout, dimensions, and plant arrangement schemes of flat beds and high beds at AVRDC, 1994/95

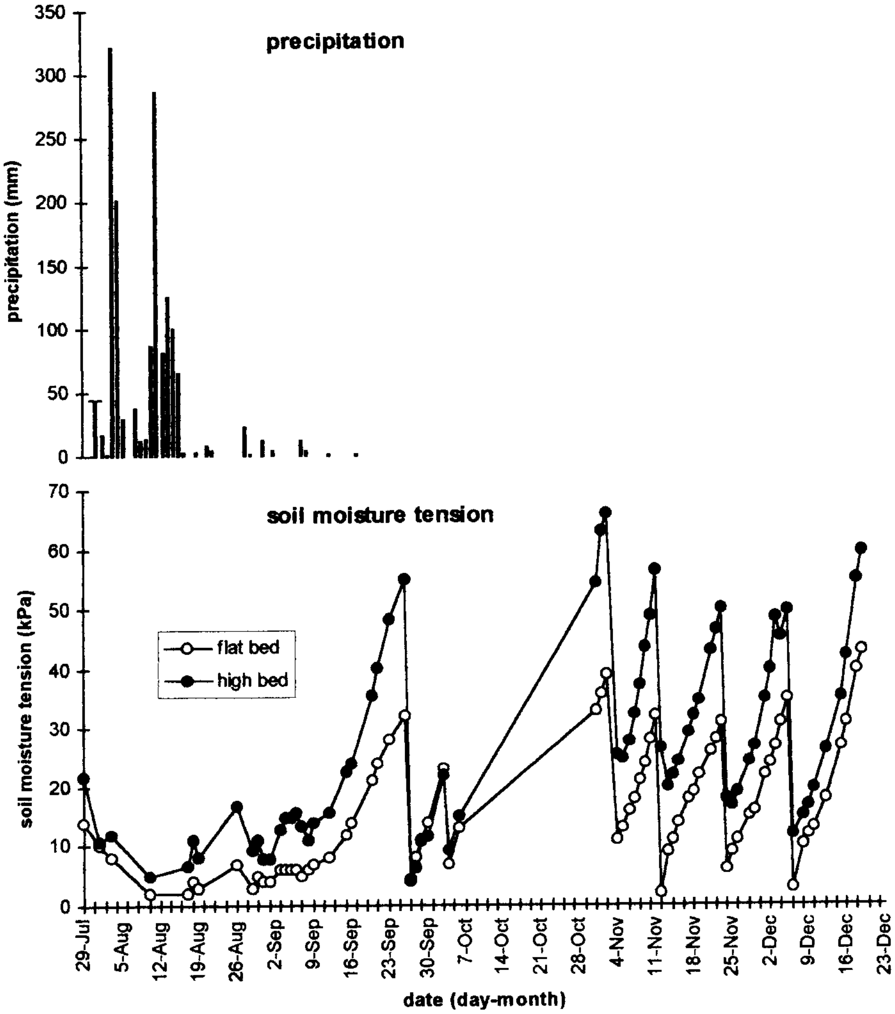

Figure 2 Daily precipitation and soil moisture tension at 15-cm soil depth in flat and high beds at AVRDC, 1994.

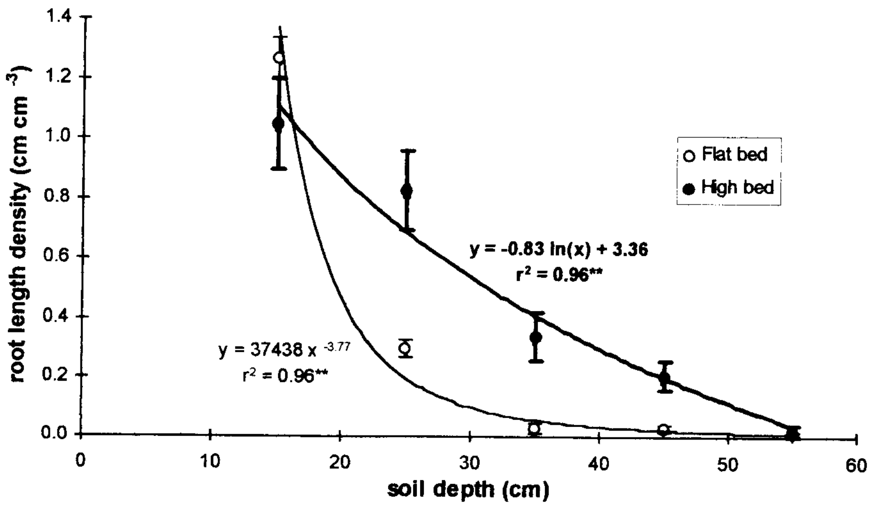

Figure 3 Root-length-density distribution of chili in flat and high beds at AVRDC, 1994. Vertical error bars indicate standard errors, lines trends for (thin line) flat beds and (thick line) high beds.

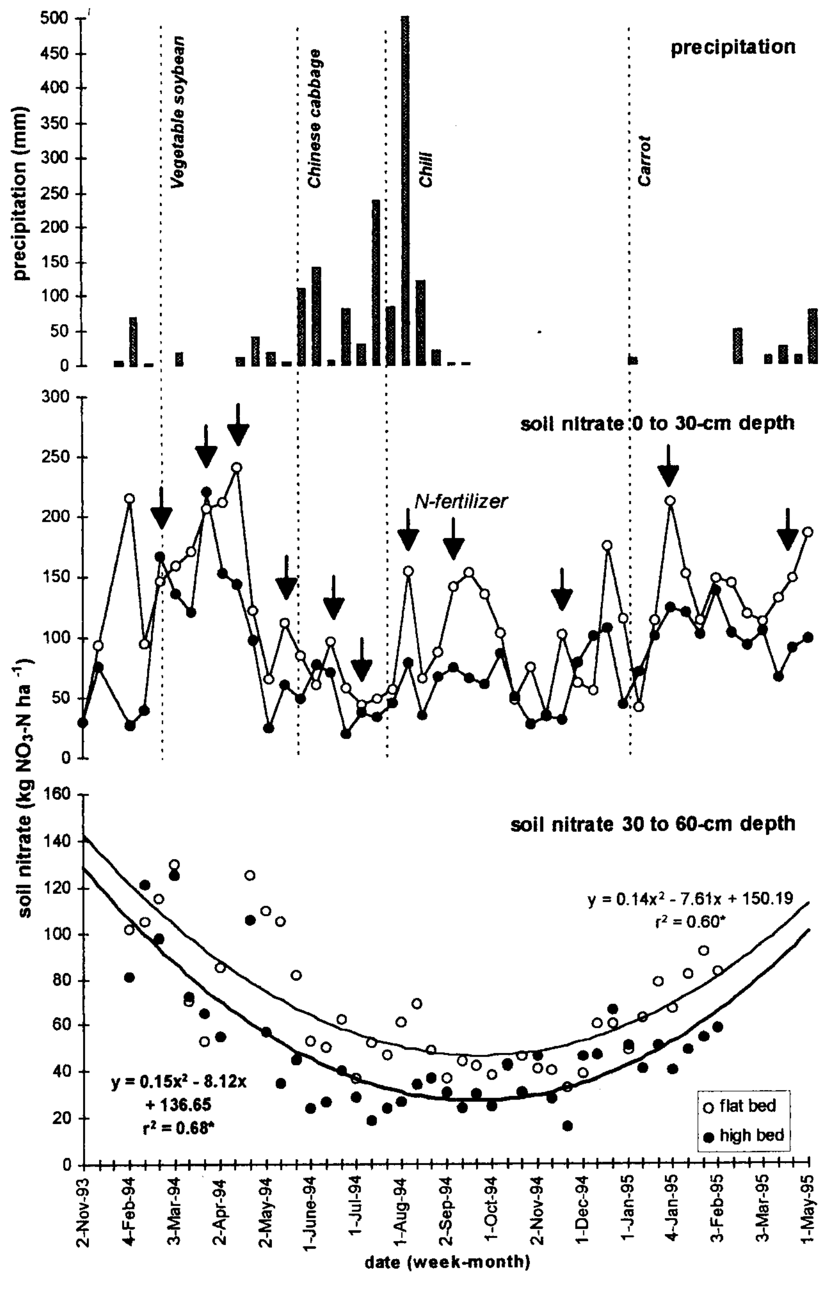

Figure 4 Weekly precipitation and effect of the standard N-application rate on mean weekly contents of soil nitrate at 0 to 30-cm and 30 to 60-cm soil depth in flat and high beds at AVRDC 1994/95. Arrows indicate application of N fertilizer, lines quadratic trends for (thin line) flat beds and (thick line) high beds.

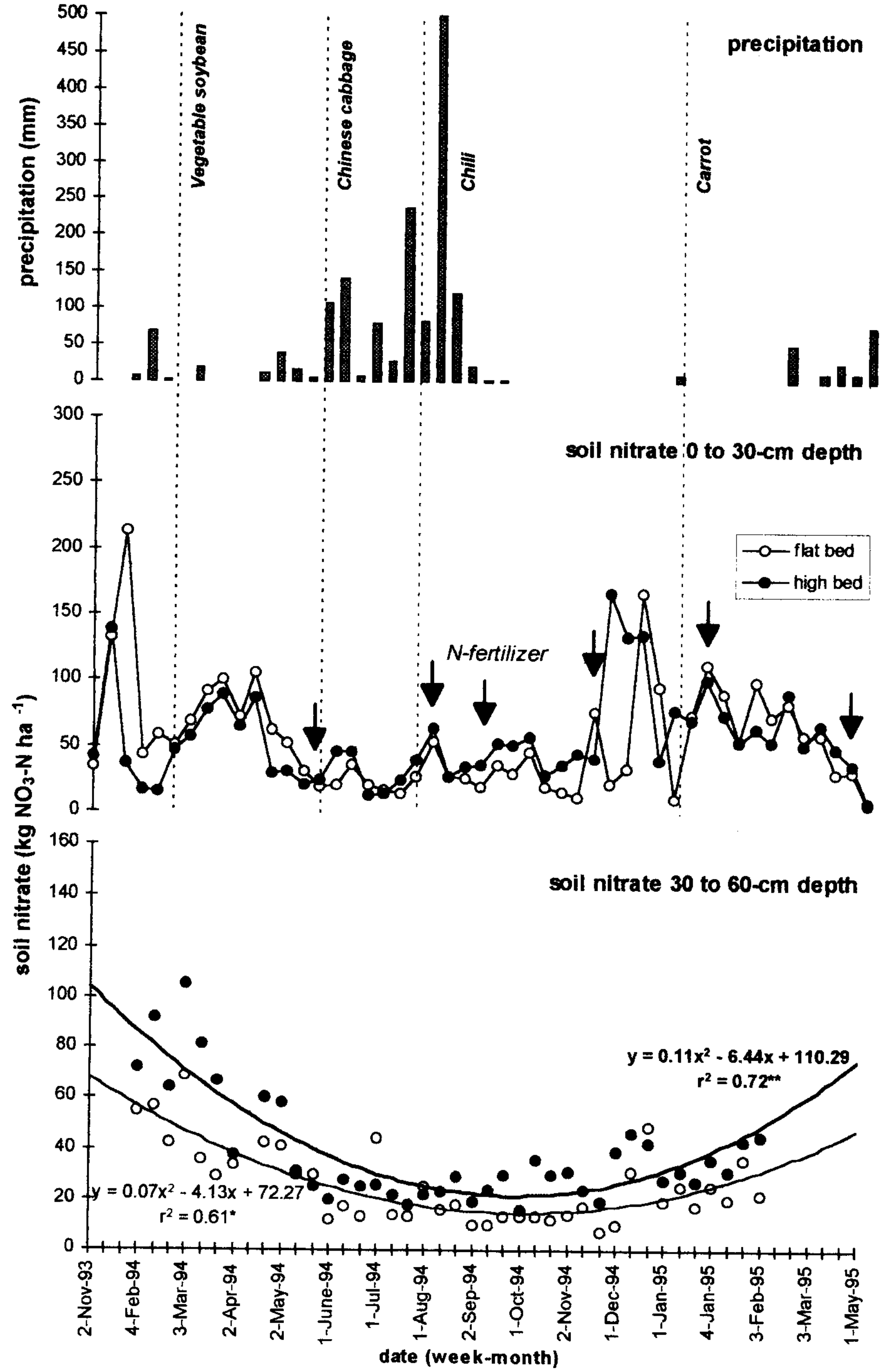

Figure 5 Weekly precipitation and effect of the N_{min}-reduced N-application rate on mean weekly contents of soil nitrate at 0 to 30-cm and 30 to 60-cm soil depth in flat and high beds at AVRDC 1994/95. Arrows indicate application of N fertilizer, lines quadratic trends for (thin line) flat beds and (thick line) high beds.