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EFFECT OF IRRIGATION AND FERTILIZATION ON THE DISTRIBUTION AND FATE OF NITROGEN IN GREENHOUSE TOMATO (*SOLANUM LYCOPERSICUM L.*)

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Abstract

A greenhouse experiment using tomato (*Solanum lycopersicum* L., cv. 'Jinpeng 10') was conducted to investigate the fate and transport of nitrogen using different methods of irrigation and fertilization. Three treatments were designed with two irrigation methods (drip irrigation and furrow irrigation) and two fertilizer application methods (fertigation and conventional fertilization). Tomato fruit yield and biomass in the fertigation treatment were significantly higher than those in the conventional fertilization treatment. The highest total uptake of nitrogen by tomato was obtained with drip fertigation and increased significantly in the conventional fertilization and CK treatments. With an increase in nitrate uptake by the fruit, the uptake of the leaf nitrogen also increased in both years of the study. The distribution of the soil nitrate-N concentration tended to be symmetrical along the center of the emitter for drip irrigation and the furrows. The nitrate-N concentration in the CK treatment was 2.85-fold higher than that in the drip fertigation treatment. The proportion of nitrogen uptake of the total nitrogen input varied from 25.38% and 53.73% in two consecutive years, and the residual nitrogen in the fertigation treatment was 48.20% and 44.64% lower than that in the CK treatment in the same two respective years.

Key words: Fertigation, Fruit yield, Nitrogen uptake rate, Soil nitrate-N content, Nitrogen residual.

Introduction

Nitrogen is a primary component of proteins and nucleotides that are essential for plants. Because most non-legume species require 20-50 g of nitrogen absorption by the roots to produce 1 kg of dry biomass, the application of fertilizer usually limits crop yields in most agricultural systems (Robertson & Vitousek, 2009). Nutrient and water management are the challenges for food security in the coming decades, and population growth and increasing consumption of calorie- and meat-intensive diets are expected to roughly double human food demand by 2050 (Tilman *et al.*, 2011). Meeting future food demand will depend on increases in agricultural production, which will increase the requirements for water. However, fresh water resources are becoming scarcer every year, and water security is threatened in many regions of the world (McDonald *et al.*, 2011). Because nutrients and water are the most important environmental factors affecting fruit growth and production of a crop, fertigation is crucial for increasing crop yields (Abdullah, 2006; Wang *et al.*, 2014). Many technological approaches to improve nitrogen management in agricultural systems have been described. The most comprehensive solutions are to redesign agricultural systems using management practices that include rotations, intercropping, and the formulation of a suitable fertilization strategy. Fertigation technology has the additional benefit of improving the absorption of soil nutrients by crops, which includes preventing the loss of fertilizer from the root zone. However, without the proper levels of irrigation and fertilizer, fertigation technology is not the most effective way to reduce nitrate infiltration (Zheng *et al.*, 2013). Therefore, studies of the effects of irrigation on soil nutrients are required, which may improve agricultural field management based on the method of irrigation.

For many plants, roots uptake and assimilate some nitrate, but most is transported to the shoot. Irrigation technology and fertilizer application method may be the most important factors influencing nitrogen transport (Amanullah *et al.*, 2009), accumulation in plant organs, mineralization, residuals and loss. Without the proper irrigation and fertilization methods, inefficient use of nitrogen can result in negative environmental effects (Kumar & Dey, 2011). Using traditional methods of nitrogen application, soils in vegetable fields become more sensitive to the accumulation of nitrate, and eventually, the leaching of nitrate occurs with furrow irrigation. Inefficient methods of irrigation and fertilization are also a possible source of nitrogen loss by nitrous oxide emission; large emissions of nitrous oxide emissions from agricultural soils can occur, depending on nitrogen application rate and method (Ren *et al.*, 2010). The common practice of applying fertilizer nitrogen in excess and traditional irrigation technology may result in relatively high rates of nitrogen loss (Ajdary *et al.*, 2007). However, currently, little information is available on rates of nitrogen loss in the vegetable systems in northwest China.

Tomato is one of the important vegetables in China because of health benefits as a good source of vitamins A and C. Therefore, more research has focused on the effects of irrigation and fertilizer application methods on tomato growth and fruit quality. With fertigation technology, fruit yields have almost doubled with improved fruit quality and water savings of 50% (Mahajan & Singh, 2006). Studies now focus more attention on the effects of irrigation strategies and fertilizer application methods on tomato growth and fruit yield and quality. However, few studies have investigated the effects of different methods of irrigation and fertilizer application on nitrogen transport, accumulation in plant organs, mineralization, residuals and loss in northwest China. Additionally, few studies have calculated the effects irrigation and fertilization methods on the balance between inputs and outputs of nitrogen. Therefore, optimal irrigation and fertilization methods for these agricultural systems must be determined. For the management of water and fertilizer in greenhouse tomato using drip irrigation fertilization, this experiment was conducted with three objectives: (1) determine the uptake of nitrogen by the different organs of tomato, (2) determine the distribution of soil nitrate-N, and (3) determine the nitrogen balance in greenhouse tomato.

Materials and Methods

Experimental site: This study was conducted during 2013 and 2014 at Yan´an University in Yan´an city (37º 04´N, 109º 05´E and altitude 1276 m) of Shaanxi Province, China. The climate is warm temperate semi-arid climate zone with a mean annual air temperature of 13°C. The mean annual precipitation was 645 mm, of which approximately 70% was rainfall between July and September, and the average annual evaporation is 1500 mm. The length of the experimental greenhouse, span and height 76 m, 7.5 m, and 2.8 m, respectively. The soil is heavy loam in texture according to the USDA texture classification system, which is derived from loess with a deep and even soil profile.

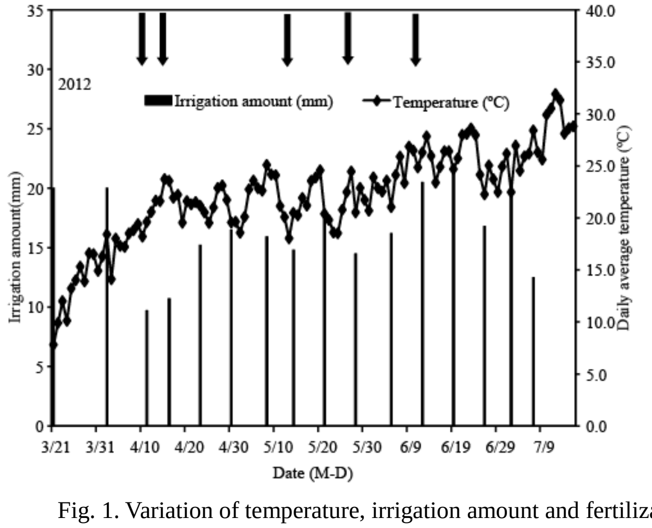
The topsoil (0-80 cm) has a pH of 8.14, and has a field capacity of 23-25% and wilting moisture content of 8.5% (above are all quality water content), an organic content of 15.02 g kg^{-1}, a total nitrogen content of 0.87 g kg^{-1}, a total phosphorus content of 0.55 g kg^{-1}, a total potassium content of 16.8 g kg^{-1}, an available nitrogen content of 78.32 g kg^{-1} and an available phosphorus of 78.32 g kg^{-1}. The atmospheric pressure, temperature, light and effective radiation (PAR), relative humidity and solar radiation are recorded automatically by an automatic weather station (HOBO event logger, USA) at the experimental site.

Experimental design: In this experiment, three treatments were designed with two irrigation methods (drip irrigation and furrow irrigation) and two methods of fertilizer application (fertigation and conventional fertilization). The experimental design was a randomized block with three replicates. Each plot was 6 m in length, 3.75 m wide and 22.5 m^2 in area. Nine experimental plots were ridged and divided by a water-stop sheet.

Tomato (*Solanum lycopersicum* L., cv. 'Jinpeng 10') was planted on 31st March in 2013 and 2014. The local, typical traditional planting patterns and calendars were followed for the cultivation of the furrow-film mulch. Tomato ridging was conducted with a tube of two line layout, spaced 50 cm, and the planting distance of 78 engrafted plants was 45 cm in each experimental plot, for a transplant density of 34,667 plants per hectare. Drip fertigation was applied with a fertilizer of urea (46% nitrogen (N)), diammonium phosphate (44% P_2O_5) and potassium chloride (60% K_2O). For fertigation, fertilizer was applied using hydraulic proportional pump control; the equipment consisted primarily of a water pump at the water source, rotor meter, and scale fertilizer pump and conveyance pipeline system. The drip line consisted of an insert cylinder head, a drip irrigation pipe with 8-mm i.d., and a drop head span of 30-cm, a head flow of 2 L h^{-1}, and a drip irrigation operating pressure of 0.3 MPa.

The surface drip irrigation system began at planting with 40 mm of irrigation. The irrigation treatments were based on the sum of evapotranspiration between two adjacent irrigation times, according to the left four-ear fruit set of 262.00 mm in 2013 and 279.54 mm in 2014. Fertilizer amount and proportions were based on (Wu *et al.*, 2015) who determined the optimum values, and the fertilizer of N (240 kg hm^{-2}), P_2O_5 (120 kg hm^{-2}), K_2O (150 kg hm^{-2}) was applied five times during tomato growth (Fig. 1): 10 and 25 days after planting and at the first, second and third fruit enlargement periods. The fertilization ratio was 1:1:2:2:2. The accurate control of irrigation water and fertilizer amount was ensured by the use of a water meter and hydraulic proportion fertilization pump.

Sampling and measurement: Plots were harvested 59, 64, 67, 72, 78, 82, 85, 88, 92, 99, 102, 110 and 113 days after transplanting (DAT) in 2013 and 61, 66, 69, 73, 77, 82, 86, 89, 95, 101, 107 and 116 DAT in 2014. A central area, 1.25 m wide, 6 m long and 7.5 m^2 in area, was harvested within each plot. Tomato fruits were graded into culls according to (Ngouajio *et al.*, 2007) grading standards for fresh-market tomato: U.S. Number 2 (medium), U.S. Number 1 (large), and Fancy (extra-large). Marketable weight was calculated as the total harvested weight minus the weight of culls. The number and weight of fruits per grading class were recorded for individual plots (Zotarelli *et al.*, 2009). The biomass accumulation of different organs was evaluated by harvesting one representative plant per treatment replicate at 113 and 116 DAT in 2013 and 2014, respectively. The roots, stems, leaves and fruits were first separated, and biomass then was measured by electronic weighing after the samples were oven-dried at 105°C for 30 minutes and then at 75°C to achieve constant weight.



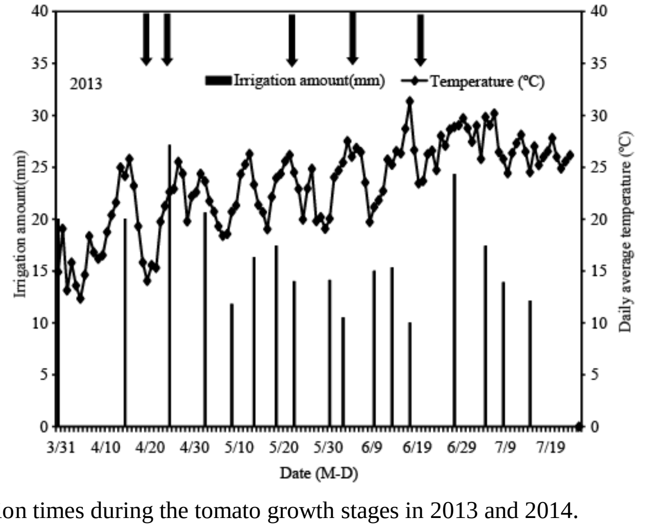


Fig. 1. Variation of temperature, irrigation amount and fertilization times during the tomato growth stages in 2013 and 2014.

Soil nitrate-N content (N=3) was measured using a spectrophotometer (UV-VIS 8500Ⅱ, China), with a depth interval of 10 cm, down to 100 cm. First, 0.5 g of fresh soil sample was placed into a 100 ml triangular flask. Then, 50 ml of 2 mol L^{-1} potassium chloride solution was added. Second, the solution was shaken a half-hour until reaching uniformity. Third, the solution was filtered, and 5 ml was placed in a spectrophotometer and examined using a 210 nm wavelength, the nitrate content was determined with colorimetric analysis. Measurements were performed at the same time of soil water content measurement (Wang *et al.*, 2015).

The samples of roots, stems, leaves and fruits were crushed and then passed through a 5 mm sieve. Boiling liquid dissipation was determined by a digestion method with H_2SO_4-H_2O_2, and the total nitrogen in plant organs was measured on a kjeltec auto-analyser (FOSS 2300).

Statistical analysis: The nitrogen harvest index (%) was equal to tomato fruit nitrogen uptake divided by total plant nitrogen uptake and multiplied by 100.

The nitrogen contribution from export (%) was equal to the amount of nitrogen accumulated divided by the amount of nitrogen fertilizer.

Nitrogen mineralization (N_m, kg hm^{-2}) was equal to the amount of nitrogen accumulated with no fertilizer added to the nitrogen residual after the end of harvest minus the nitrogen content before transplanting.

The nitrogen content in the 0-60 cm soil layer before transplanting (N_c, kg hm^{-2}) and the residual nitrate-N (N_r, kg hm^{-2}) were determined using the following equation:

$$A= c\times h\times \rho\times 10\times 0.01 \qquad (1)$$

where c is soil nitrate-N concentration (mg kg^{-1}), h is soil depth (cm), and ρ is soil bulk density (g cm^{-3}).

Nitrogen uptake (N_u, kg hm^{-2}) was equal to the content of nitrogen multiplied by the biomass of different organs.

Nitrogen loss (N_l, kg hm^{-2}) was equal to the nitrogen in fertilization added to the amount of residual nitrate-N in the preliminary stage and the amount of soil nitrogen mineralized minus the nitrogen accumulated and the residual nitrate-N in the last phase.

The nitrogen balance was calculated using the following equation:

$$N_f+N_c+N_m=N_u+N_r+ N_l \qquad (2)$$

where N_f is nitrogen fertilization, N_c is nitrogen content in 0-60 cm soil layer before transplanting, N_m is nitrogen mineralization, N_u is nitrogen uptake, N_r is residual nitrogen after harvest in the 0-60 cm soil layer, and N_l is nitrogen loss over the entire growing season (Patil *et al.*, 2001).

Results

Tomato yield and biomass accumulation: The tomato yields obtained in both years are shown in Fig. 2. The yields clearly varied widely in two consecutive years, from 66.11 to 97.15 t hm^{-2}, depending on the different methods of irrigation and fertilization. Both irrigation (drip irrigation and furrow irrigation) and fertilization (drip fertigation and conventional fertilization) methods had significant ($p<0.05$) effects on marketable yield; therefore, the interaction effect between the two factors was significant. The maximum yield was obtained with the drip irrigation and drip fertigation treatment in both years; the yield was 96.72 and 97.15 t hm^{-2} in 2013 and 2014, respectively, which was 28.88% and 31.95% higher than that in the CK treatment in the two years, respectively. The yield of the drip irrigation and conventional fertilization treatment was significantly higher than that of the CK treatment by 14.24% and 15.87% in the two consecutive years, respectively.

An interaction between irrigation and fertilization was detected for tomato biomass accumulation, with important effects of the different methods on biomass accumulation (Fig. 3). The use of drip fertigation increased total biomass accumulation by 41.22% in 2013 and 35.09% in 2014 when compared with that in the CK treatment. The differences in tomato leaf, stem and fruit biomass accumulation between drip fertigation and drip irrigation and conventional fertilization treatments were significant, but biomass accumulation in tomato roots was not significantly different. Of the tomato organs, fruits accumulated the most biomass, with the proportion of biomass accumulation varying widely from 51.73% to 62.59% in both years. The lowest biomass accumulation was in roots, which ranged from 1.66% to 2.77% of the entire plant.

Nitrogen uptake in organs: The effects of the different irrigation and fertilization methods on the uptake of nitrogen in different organs in two consecutive years are shown in Table 1. The total uptake of nitrogen was significantly ($P<0.01$) influenced by irrigation and fertilizer methods in both years. In 2013, the highest total uptake of nitrogen was 211.19 kg hm^{-2} with drip fertigation, and uptake also increased significantly in the conventional fertilization (22.63%) and CK (52.77%) treatments. In 2014, the total uptake of nitrogen was 161.80 kg hm^{-2} with drip fertigation, and uptake increased significantly and comparably in conventional fertilization and CK treatments (36.04% and 62.59%, respectively). The total uptake of nitrogen was significantly higher in 2013 than that in 2014. In both years, the nitrogen uptake in fruit was significantly affected by the irrigation method, the fertilizer application method and the interaction. As the uptake of nitrogen in fruit increased, the leaf uptake of nitrogen also increased in both years. The changes in uptake of nitrogen were as follows: root < stem < leaf < fruit. In 2013, when comparing fertilization methods, the uptake of nitrogen in fruit in the fertigation treatment was 20.99 kg hm^{-2} higher than that in the conventional fertilization treatment, and when comparing irrigation methods, the uptake of nitrogen in fruit in the drip irrigation treatment was 15.79 kg hm^{-2} higher than that with furrow irrigation. The results were similar in 2014.

The nitrogen harvest index ranged from 43.42% to 56.63% in the two years; the nitrogen harvest index was negatively correlated with the total uptake of nitrogen. The highest nitrogen harvest index was obtained in the CK treatment, but no significant difference was detected between fertigation and conventional fertilization treatments. The contribution of nitrogen from exportation was the highest in the fertigation treatment in 2013 at 88%, which was significantly higher than that in conventional fertilization and CK treatments. The contribution of nitrogen from exportation in 2013 was higher than that in 2014.

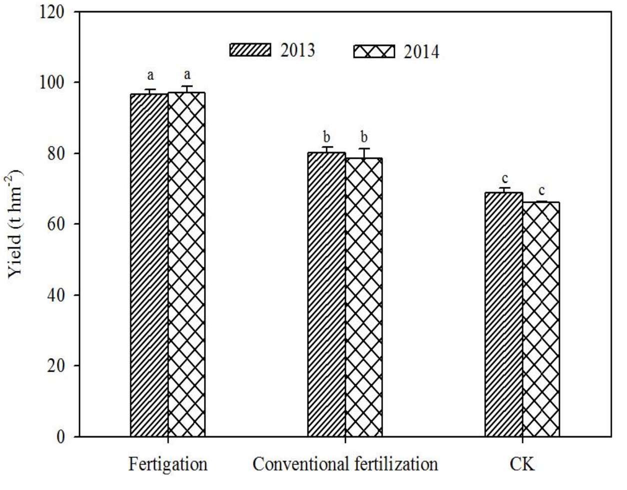


Fig. 2. Effect of different treatments on tomato yield, the fertigation treatment was drip irrigation and drip fertilization, the conventional fertilization treatment was drip irrigation and conventional fertilization, the CK treatment was furrow irrigation and conventional fertilization, and all treatments have the same levels of irrigation (262.00 mm, 269.54 mm in 2013 and 2014, respectively) and fertilization (240 N kg hm^{-2} in both years) amount.

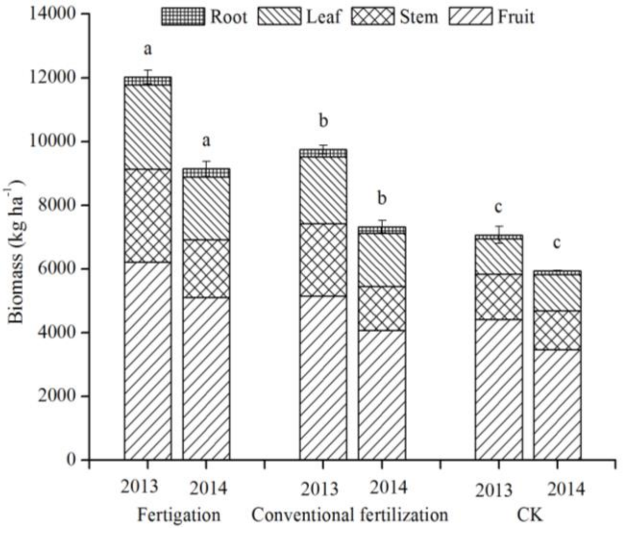


Fig. 3 Effect of different irrigation and fertilization methods on different organs biomass accumulation in 2013 and 2014, values followed by different letters in a column is significantly different among treatments at the 5% level.

Table 1. Effect of nitrogen accumulation in different organs on different irrigation and fertilization methods in two consecutive years.

Year	Treatment	N accumulation in different organs (kg hm^{-2})				Total N (kg hm^{-2})	N harvest index (%)	N contribution rate (%)
		Fruit	Stem	Leaf	Root			
2013	Fertigation	91.69±2.01	45.41±2.66	70.04±0.1	4.25±0.13	211.19±4.91	43.42	88.00
	Conventional fertilization	70.70±0.21	31.41±1.22	57.17±2.85	4.13±0.17	163.41±1.58	43.27	68.09
	CK	54.91±3.54	11.58±1.05	31.39±2.6	1.91±0.16	99.77±7.34	55.04	41.57
2014	Fertigation	86.33±10.99	17.87±1.04	51.86±1.73	5.74±0.08	161.80±13.84	53.36	67.42
	Conventional fertilization	63.12±1.82	13.54±1.44	38.23±2.1	4.69±0.08	119.68±5.28	52.73	49.87
	CK	50.28±3.15	11.12±0.13	25.27±2	2.12±0.06	88.79±5.35	56.63	37.00

Table 2. The nitrogen input and output balance of nitrogen fertilization (N_f), nitrogen content before transplanting (N_c), nitrogen mineralization (N_m), nitrogen uptake rate (N_u), nitrogen residual (N_r), and nitrogen loss (N_l) in the whole growing season in 0-60 cm soil layers in different irrigation and fertilization method.

Year	Treatments	Nitrogen input (kg hm^{-2})			Nitrogen output (kg hm^{-2})		
		N_f	N_c	N_m	N_u	N_r	N_l
2013	Fertigation	240.00	112.39	40.69	211.19	78.10	103.79
	Conventional fertilization	240.00	112.39	40.69	163.41	110.76	118.91
	CK	240.00	112.39	40.69	99.77	150.78	142.53
2014	Fertigation	240.00	78.95	28.42	161.80	71.06	114.51
	Conventional fertilization	240.00	78.95	28.42	119.68	102.26	125.43
	CK	240.00	78.95	28.42	88.79	128.35	130.23

Soil nitrate-N concentrations: The dynamics of soil nitrate-N concentrations in the root region for the different irrigation and fertilization treatments in both years are shown in Fig. 4. A large difference in the horizontal distribution of soil nitrate-N was detected in the 0–30 cm layer after harvest. The distribution of soil nitrate-N tended to be symmetrical along the centre of the emitter for drip irrigation and the furrows. The standard symmetrical distribution was reduced gradually with soil depth but persisted under the drip irrigation methods. The nitrate-N concentration in the root absorption area was higher than that in the other areas. Based on the results, high levels of nitrate-N were primarily distributed in the 0–10 cm layer, and the nitrate-N concentration in the CK treatment was 2.85-fold higher than that in drip fertigation treatment. The nitrate-N content in the root zone was lower in the soils of the fertigation treatment than in those of the CK treatment. The soil nitrate-N concentration below 30 cm was not significantly different between fertigation and CK treatments.

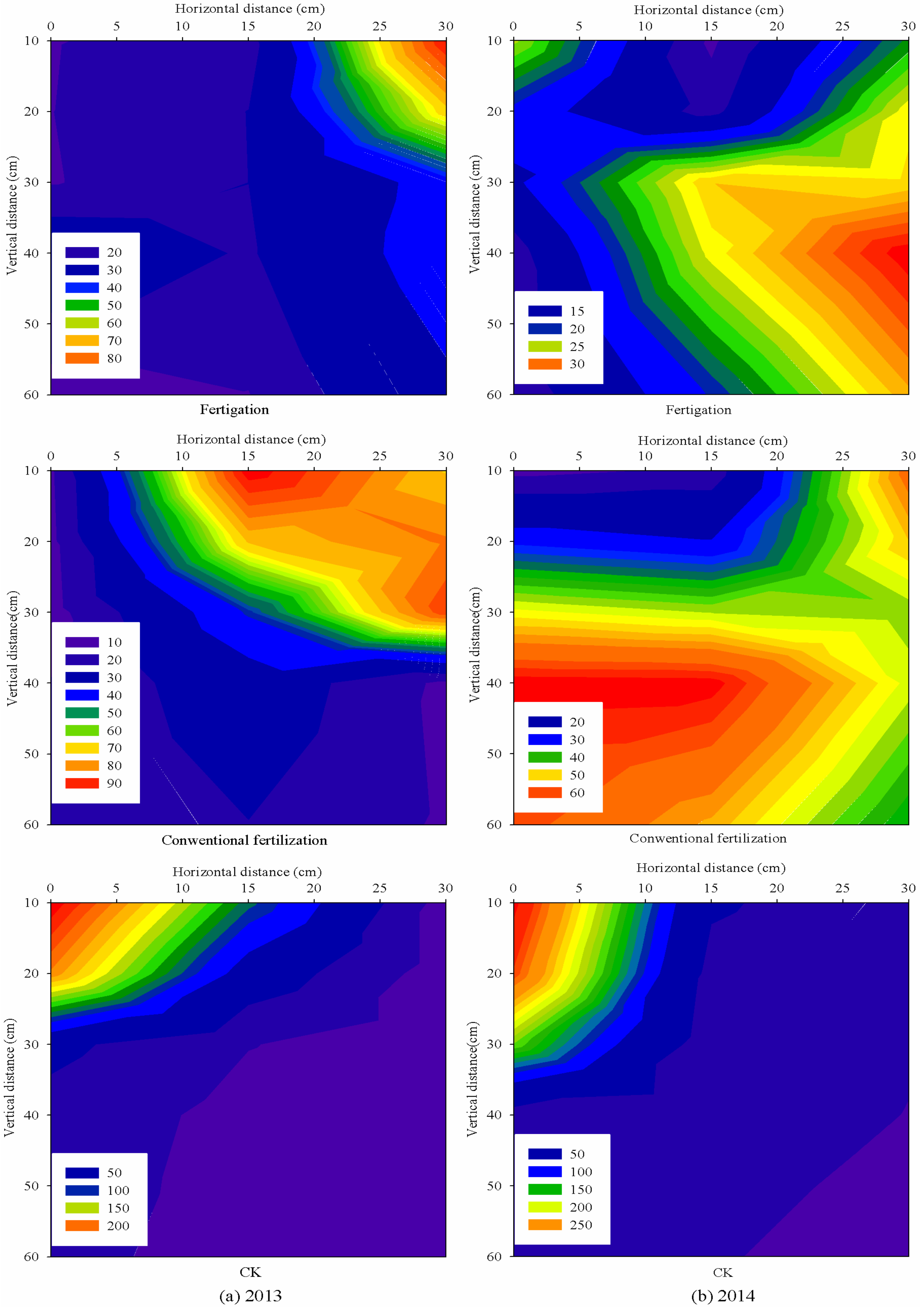


Fig. 4. Dynamics of soil nitrate-N concentration in the root zone using different irrigation and fertilization methods in 2013 and 2014.

Nitrogen balance: For this study, the amounts of nitrogen applied with drip fertigation and conventional treatments are shown in Table 2. The total nitrogen input, including fertilizer, mineralization and residual nitrogen, was 393.08 and 347.37 kg hm^{-2} in 2013 and 2014, respectively. In both years, the nitrogen content in the 0-60 cm soil layer before transplanting and nitrogen mineralization were different, and the uptake of nitrogen by tomato organs was also different, but the uptake of nitrogen was positively correlated with nitrogen content before transplanting. The proportion of nitrogen uptake of the total nitrogen input varied from 25.38% to 53.73% in the two consecutive years, compared with only 25.38% and 25.56% in the CK treatment in the two years, respectively. The uptake of nitrogen in the fertigation treatment was 111.42 and 73.01 kg hm^{-2} higher than that in the CK treatment in 2013 and 2014, respectively where as for the conventional fertilization treatment, the uptake was 63.64 and 30.89 kg hm^{-2} higher than that in the CK treatment in the two years, respectively. Residual nitrogen was significantly affected by irrigation and fertilizer methods in both years. In the fertigation treatment, residual nitrogen was 48.20% and 44.64% lower than that in the CK treatment in 2013 and 2014, respectively, and in the conventional fertilization treatment, residual nitrogen was 26.54% and 12.54% lower than that in the CK treatment in the two years, respectively. When residual soil nitrate and nitrogen fertilizer application from drip irrigation, furrow irrigation, fertigation and conventional fertilization were compared with the CK treatment, the apparent nitrogen loss was reduced from 14.80 to 38.74 kg hm^{-2}. Of the nitrogen fertilizer applied, the proportion of nitrogen lost ranged from 43.25% to 59.79%.

Discussion

Tomato fruit yield and biomass were higher with fertigation treatment than with conventional fertilization, which might be the result of increased nitrogen accumulation or nitrogen use efficiency in the fertigation treatment. Additionally, the distribution of nitrate-N in the soil in the root region was more uniform in the fertigation treatment than that in the conventional fertilization treatment. Because of these differences, the tomato yield and biomass and uptake of nitrogen in organs were also higher in another study with drip fertigation treatment (Singandhupe *et al.*, 2003). The results of the current study are also consistent with those of Mahajan & Singh (2006) who observed improved growth, particularly in the early stage, and increased fruit yield for greenhouse tomato with fertigation. Fertigation effects on tomato yield are dependent on the soil moisture or wetness of an area and the uniformity of fertilizer application, and fertigation is more beneficial when the soil profile is almost wetted by the front edge of irrigation (Badr *et al.*, 2010). In our study, tomato yield in the fertigation treatment was 28.88% and 31.95% higher than that in the CK treatment in two consecutive years. A similar result was obtained with fertigation using 100% water-soluble fertilizer, and fruit yield increased by 33% compared with furrow irrigation (Hebbar *et al.*, 2004).

In the fertigation treatment, the increase in fruit yield was the result of an increase in biomass accumulation, with the additional result of reduced leaching of nitrogen to deeper layers of the soil. By contrast, in northern China, furrow irrigation was the primary factor for significant nitrogen loss (He *et al.*, 2006). The decrease in leaching of nitrogen in the fertigation treatment was likely due to the increase in availability of nutrients in the root zone, which was coupled with improved root activity because of the frequent application of nutrients. In addition to root uptake, nitrogen concentrations also increased in stems, leaves and fruits when fertilizer was applied through fertigation, which further decreased the nitrogen that could be leached. Similar increases in nitrogen uptake using fertigation were observed earlier by (Farneselli *et al.*, 2015). Increasing the contribution of nitrogen to the plant can decrease nitrogen losses from soil, whereas increasing the nitrogen harvest index can decrease the nitrogen concentrations in plants. The contribution of nitrogen in the fertigation treatment was 88.00% in 2013, whereas the contribution in the CK treatment was only 41.57%. Thus, by improving the fruit yield per unit of nitrogen applied, the contribution of nitrogen can be increased; because the uptake of nitrogen in tomato is first distributed into fruit and then into the vegetative organs at later developmental stages. Additionally, with the increased uptake of nitrogen, there is relatively less residual nitrogen (Xu *et al.*, 2012).

Total nitrogen inputs and outputs were by determined by considering nitrogen fertilization and removal, readily available nitrogen and soil nitrate-N in the irrigation water. In the fertigation treatment, 211.19 kg hm^{-2} and 161.80 kg hm^{-2} were removed in 2013 and 2014, respectively. Much nitrogen was removed in plant organs regardless of the irrigation technique. In the fertigation treatment, the soil application of fertilizers led to over 80% of the nitrogen accumulated in crop aboveground parts, which resulted in 60% of crop nitrogen translocated to fruit yield (Darwish *et al.*, 2003). The dynamics of nitrogen accumulation and translocation within the plant can be gauged from the changing pattern of source and sink interactions (Cabello *et al.*, 2011). Increasing nitrogen recovery based on crop response, soil and water conditions could lead to reductions in residual soil nitrogen. In this study, the concentration of nitrate-N was high below the rooting level in the fertigation treatment, and the distribution of soil nitrate-N in the root region was slightly higher than that in the CK treatment.

Conclusion

The tomato fruit yield and biomass in the fertigation treatment were significantly higher than those in the conventional fertilization treatment. The distribution of soil nitrate-N concentrations tended to be symmetrical along the centre of the emitter and the furrows, and the nitrate-N concentration in the CK treatment was 2.85-fold higher than that in the drip fertigation treatment. In the fertigation treatment, the proportions of nitrogen uptake were 46.58% and 53.73% of the total nitrogen input in two consecutive years which significantly higher than that in conventional fertilization and CK treatments. Although important achievements and incorporation of new activities have occurred in field management practices, traditional cultivation without drip irrigation remains the common practice. Thus considerable effort will be required to achieve widespread application of fertigation. Fertigation is recommended because tomato yield increased by 28.88% and 31.95% compared with the CK treatment (conventional fertilization and furrow irrigation) in two consecutive years.

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