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Effects of Different Kinds of Fertilizer and Application Methods on $\delta^{15}N$ Values of Tomato

Akimasa NAKANO* **and Yoichi UEHARA**

Advanced Protected Cultivation Team, National Research Institute of Vegetables and Tea Science (Taketoyo, Aichi 470–2351, Japan)

Abstract

Effects of different kinds of fertilizer and application methods on tomato yields and inorganic nutrient contents were investigated. The contribution of nitrogen usage to tomato production for each fertilizer application was also estimated by the stable isotope ratio of nitrogen. LSR (low sulfate slow-release fertilizer, LSR plot), daily application of liquid OK-F-1 fertilizer (OK-F-1 plot) and PEL (manure pellet fertilizer, PEL plot) yielded most among the eight different treatments. Fruit quality as measured by nitrogen content (related to amino acid content) was higher in the OK-F-1 treatment. In the conventional fertilization of mixing fertilizer in soil, roots absorbed soil nitrogen which affected the $\delta^{15}N$ values of fruits, while in the daily application of liquid fertilizer (fertigation) there was little observed influence of soil nitrogen on the $\delta^{15}N$ values of the upper parts of tomato. These results suggested that fertigation is an effective fertilization method which preserved soil nitrogen.

Discipline: Soils, fertilizers and plant nutrition
Additional key words: organic products, quality, stable isotope

Introduction

Different kinds of fertilizer and application methods have different effects on the yields and quality of tomato fruits. Especially, consumers have an increasing interest in organic products because they are thought to be environmentally sound or of high quality[2]. The situation is the same in Japan and laws governing certification of organic products have been in effect in Japan since April 2001. Although many comparisons of organically and conventionally grown food have been reviewed in the relevant literature[10], differences between varieties and other environmental conditions had a far greater influence on fruit quality than did the different cultivation systems including organic or inorganic. More information and scientific results are needed to reveal the mechanism for producing fruit of high yield and quality.

In this study, the effect of fertilizer used in environmentally sound agriculture (e.g. slow release fertilizer and manure pellet fertilizer) as well as fertilizer application methods (fertigation) on the yield and quality (mineral content) were inspected. The $\delta^{15}N$ values used to differentiate between vegetables grown by organic and inorganic fertilizer or by fertigation systems was proposed[3,5] for other kinds of fertilizer. The $\delta^{15}N$ value was applied to ensure this identification criterion. The nitrogen stable isotopes composition of a substance is expressed in relation to an international reference standard (air). $\delta^{15}N$ = [R sample/R standard –1] × 1,000(‰). Stable isotope analysis has been increasingly used to ensure geographic origin of certain products[9] and nutrient cycling of the agro-ecosystem[11].

So far, $\delta^{15}N$ values were adopted as a marker for distinguishing organic products from conventional products for five vegetables (tomato, cucumber, eggplant, green pepper, and pumpkin). The values available for all certified organic products have higher $\delta^{15}N$ values than the ordinal products[3]. Further, on the study of multi element isotope ratios ($\delta^{34}S$, $\delta^{18}O$ and $\delta^{15}N$) of vegetables from integrated and organic production, no differences in the $\delta^{34}S$ or $\delta^{18}O$ values of the vegetables grown under the integrated or organic production systems were observed. However, the organically produced vegetables were significantly enriched in ^{15}N[1] and therefore it is the most appropriate indicator.

In this study, we also attempted to extend $\delta^{15}N$ values usage in order to identify fertilization distribution by adopting other different fertilizers and fertilization methods and evaluating the amount of fertilized nitrogen

*Corresponding author: e-mail anakano@affrc.go.jp
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absorbed by the fruits as well as the resulting yields to use the $\delta^{15}N$ value as a tracer.

Materials and methods

1. Plant cultivation

Field soil (sandy clay loam) from the National Research Institute for Vegetables and Tea Science (Taketoyo) was sieved through a 1 cm mesh and mixed with bark compost (soil : bark, 4:1) in order to improve water permeability of the growth medium used in the experiment. Fertilizer described in Table 1 was mixed with 11 L of the medium and put in a plant pot (height: 22 cm, average diameter: 25 cm). There were 8 experimental plots consisting of a no fertilizer treatment (control; Cont.) and 7 different fertilizer treatments including 5 chemical fertilizers, S604 (readily available fertilizer), CDU mixed fertilizer (CDU (cyclo-di-urea) S222, containing readily and slowly available fertilizer), LSR (low sulfate slow-release fertilizer), LP (coated fertilizer, half life 140 days), and OK-F-1 (fertilizer for fertigation), as well as 2 organic fertilizers, CM + PM (mixture of cattle and poultry manure) and manure pellet fertilizer (mixture of cattle and poultry manure in a diameter of 5 mm × 7 mm pellets). Except for the OK-F-1 plot, the total amount of 5 gN/pot applied nitrogen was the same for the fertilizers described above and was mixed in each of these treatments on 25 September 2003. In the OK-F-1 plot, the same amount of nitrogen was divided by the days of application and applied daily at 83 mgN/plant/day average nitrogen application rate. On 26 September 2003, 40-day-old tomato seedlings of ‘Renaissance’ (parthenocarpic variety) grown in plug trays were transplanted to each pot. There were 3 replications for each treatment. At transplanting, 1 L of tap water was used to initially irrigate, after that each pot was irrigated with 0.3 L of tap water for 30 days followed by irrigation with 0.5 L of tap water for 23 days.

2. Tomato fruit yield, shoot and root production

On 18 November 2003, 53 days after transplanting the seedlings, fruits and shoots were harvested and fruit fresh weight was measured. At the same time, the roots were removed from soil and the soil was well mixed and sampled. After soil sampling, roots were washed to remove soil. Shoots and roots were oven-dried at 80ºC for 72 h and dry weight was measured. Fruits were freeze-dried for 72 h.

3. Nitrogen content and $\delta^{15}N$ value of fertilizer, soil, shoot, and fruit

Fertilizers, soils, shoots, and roots were oven-dried at 80ºC. These and freeze-dried fruit materials were pulverized. The samples were enclosed in tin cups and analyzed by mass spectrometry (ANCA-SL, Europa Scientific, UK) to determine the $\delta^{15}N$ values and nitrogen contents. Nitrogen contents of fertilizer were measured by Kjeldahl method (KJELTEC AUTO 1030 Analyzer, Tecator AB, Sweden).

4. Chemical properties of soil extract and fruit

Soil extract was prepared by shaking soil with distilled water in bottles at the ratio of one part dried soil to five parts water for 30 min. The electric conductivity (EC) of the soil extract was measured by EC meter (CM-30V, TOA, Japan) and the pH of the soil extract was measured by pH meter (M-12, Horiba, Japan). The freeze-dried fruits were digested by concentrated nitric acid. The potassium, phosphate, calcium, and magnesium of the soil extract and the digested solution were measured by ICP (SPS, 7700, Seiko Instrument, Japan) and nitrate, chlorite and sulfate of soil extracts were measured by ion chromatography (LC-10AD, Shimadzu, Japan)[4].

Results

1. Characteristics of fertilizer

Chemical composition of applied fertilizer is described in Table 1. The five chemical fertilizers contained the following range of NPK: nitrogen 11 to 16%, phosphate 8 to 12% and potassium 11 to 17%. On the other hand, the two organic fertilizers contained the following range of NPK: nitrogen 2.2 to 3.5%, phosphate 1.9 to 5.6% and potassium 2.5 to 3.0%, which was around one third of the chemical fertilizer contents. Organic fertilizer contained greater ratios of calcium and magnesium than chemical fertilizer did.

2. Effect of fertilizer on the growth of tomato

Every fertilized plot had a heavier shoot weight than the no fertilizer plot (Cont.) described in Fig. 1, though fertilization effects were different among treatments. In general, the growth of chemical fertilizer plots was better, especially the S604 plot to which more readily available nitrogen was applied, and the OK-F-1 plot to which the daily application of liquid fertilizer lead to higher nitrogen use efficiency. This was followed by the CDU plot which consisted of about 60% readily available nitrogen and 40% slow-release nitrogen. The LP plot to which coated fertilizer was applied had lighter shoot weight among the chemical fertilizer plots. Of the organic fertilizer treatments, the CM+PM plot had lighter shoot weight than the PEL plot, which had the lowest shoot weight among all treatments.

While root weight had the same tendency of shoot

Table 1. Contents and $\delta^{15}N$ values of fertilizer

Fertilzer	Treatment	N	P_2O_5	K_2O (g kg^{-1})	CaO	MgO	$\delta^{15}N$ values (‰)
Chemical fertilizer	S604	160	100	140	75*	5*	+ 0.5
CDU compound fertilizer	CDU	120	120	120	23*	46*	– 1.8
Low sulfate slow-release fertilizer	LSR	110	110	110	43*	50*	+ 0.6
Coated chemical fertilizer	LP	140	120	140	42*	5*	+ 0.2
Fertilizer for fertigation	OK-F-1	150	80	170	60	20	– 0.7
Cattle manure	CM+PM	25**	25*	30*	24*	13*	+ 16.7
+poutry manure		22**	56*	25*	182*	17*	
Manure pellet	PEL	35**	19*	29*	22	12*	+ 9.9

Guaranteed content, *: measured by ICP, **: measured by Kjeldahl method.

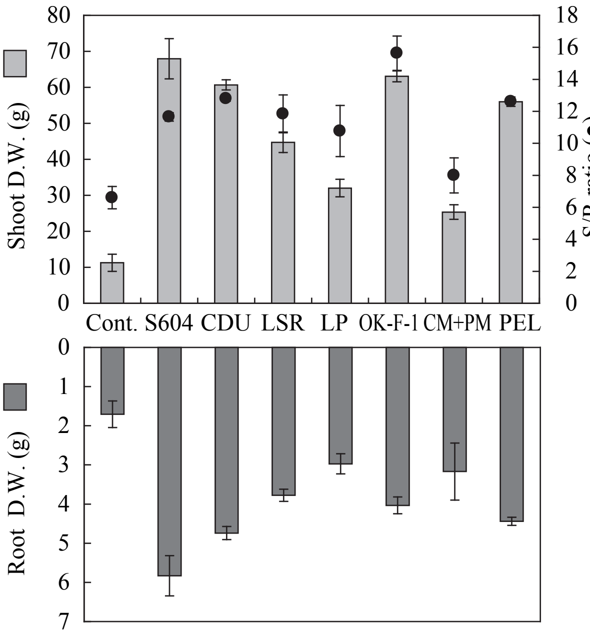

Fig. 1. Effects of different kinds of fertilizer and application methods on the shoot and root dry matter weight and S/R ratio of tomato
Vertical bars indicate SD of 3 samples.

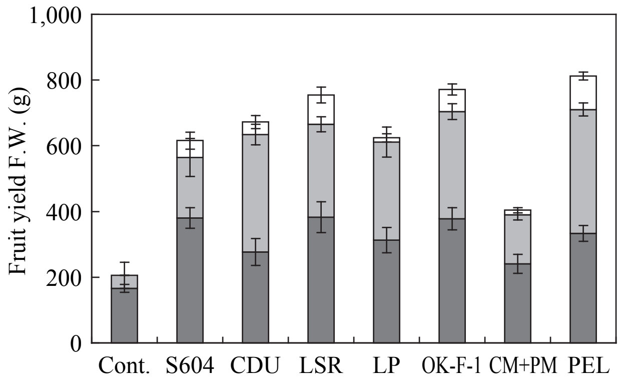

Fig. 2. Effects of different kinds of fertilizers and application methods on the yield of tomato
■: 1st truss, ▨: 2nd truss, □: 3rd truss.
Vertical bars indicate SD of 3 samples except for 2nd truss of tomato control plot (n = 1) and 3rd truss of tomato CDU, LP and CM+PM plots (n = 2, 1, 2, respectively).

weight, the S/R ratio also showed the same tendency of shoot weight. These results meant that in these plots of restricted growth, shoot growth was more restricted than root growth. The highest S/R ratio was that of the OK-F-1 plot.

3. Effect of fertilizer on the yield of tomato

Of the total yields, PEL, OK-F-1 and LSR plots had higher yields, while the CM+PM plot had the lowest yield (Fig. 2). Yields of the first truss were similar at about 200 g of fruit, while on the second truss the yield differed among treatments. However, the S604 plot, which had yields similar to other chemical fertilizer plots of the first truss, had a more reduced yield than the other chemical fertilizer plots on the second truss. At the third truss, the yields of the LP and CM+PM plots, which were supposed to be lower in nutrients from fertilizer, had reduced yields. On the other hand, LSR, OK-F-1 and PEL plots showed higher third truss fruit yield.

4. Chemical properties of soils of after cultivation

Electric conductivity (EC) of soil extract was relatively higher for the CDU treatment plot which contained more readily available nutrients, followed by the S604 plot which also had relatively more such nutrients. While EC of the LSR plot which contains restricted sulfate and

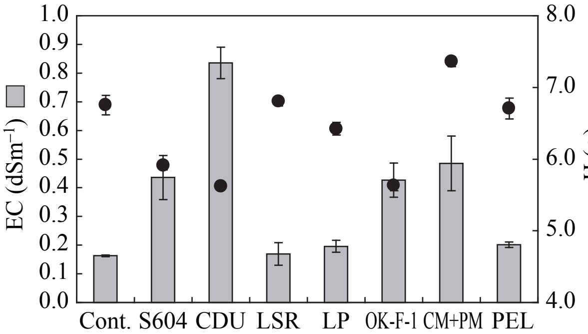

Fig. 3. Electric conductivity (EC) and pH of the 1:5 soil extract after cultivation

Vertical bars indicate SD of 3 samples.

chloride as well as EC of the LP coated fertilizer plot was suppressed (Fig. 3). For the organic fertilizer, EC of the PEL plot was lower than that of the CM+PM plot. The pH values of chemical fertilizers were from 5.8 to 6.8, which was more acidic compared with the organic plots with pH of 6.7 (PEL plot) and 7.4 (CM+PM plot). Total ion content of the soil after cultivation was correlated to EC; the CDU plot had the highest concentration with LSR, PL and PEL plots having lower values (Fig. 4). For the chemical fertilizer plots, total anion concentration (NO_3^-, SO_4^{2-} and Cl^-) was higher than the total cation concentration (K^+, Ca^{2+} and Mg^{2+}), on the other hand, for the organic fertilizer plots, CM+PM and PEL, cation concentration exceeded anion concentration. Even though we should determine these concentrations more precisely, there was a tendency for the soil solution in which more anions were present than cations to become more acidic and vice versa.

5. Effect of fertilizer on the $\delta^{15}N$ values of the soil, shoots and fruits of tomato

The $\delta^{15}N$ values of fertilizers described in Table 1 and Fig. 5A had values for chemical fertilizer of around 0‰; S604: +0.5‰, CDU: –1.8‰, LSR: +0.6, LP: +0.2, and OK-F-1: –0.7‰. On the other hand, organic fertilizer had higher $\delta^{15}N$ values; PEL: +9.9‰ and CM+PM: +16.7‰. The $\delta^{15}N$ values of the soil reflected the value of the fertilizer, whose distribution was narrower than that of fertilizer. For the chemical fertilizer plots, from a minimum in the OK-F-1 plot of +3.7‰ to the maximum in the LSR plot of +5.7‰, there was a range of 2‰ for the soil. For the organic fertilizer plots, from a minimum in the PEL plot of +7.1‰ to a maximum in the CM+PM plot of +9.1‰, there was a range of 2‰ for the soil (Fig. 5). On the whole, $\delta^{15}N$ values for the soil from +3.7‰ to +9.1‰ were restricted to a relatively narrower range of 5.4‰.

The $\delta^{15}N$ values of shoots and fruits were similar to those of the fertilizer applied for the organic fertilizer,

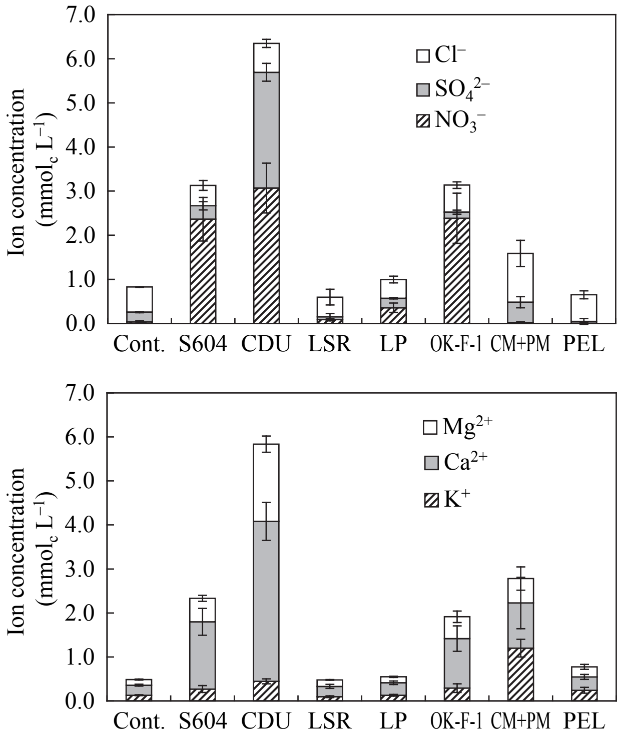

Fig. 4. Effects of different kinds of fertilizer and application methods on the ion concentration of the 1:5 soil extract after cultivation

Vertical bars indicate SD of 3 samples.

while for the chemical fertilizers these values were between the $\delta^{15}N$ values of the fertilizer applied and the soil, which was different among the fertilizers. The $\delta^{15}N$ values of the fruit were below +3.1‰ for the chemical fertilizers and above +8.7‰ for the organic fertilizers. The fluctuation in the $\delta^{15}N$ values among the trusses had a narrow range, i.e. CM+PM with range of +14.9 to +15.4‰ (0.5‰) and PEL with range of +8.7 to +10.6‰ (1.9‰) (Fig. 5B). While for the chemical fertilizer treatments, LSR, LP and OK-F-1 plots, whose fluctuation of $\delta^{15}N$ values, was narrower among trusses, i.e. LSR with a range of +2.2 to +3.1‰ (0.9‰), LP with a range of +1.7 to +2.7‰ (1.0‰) and OK-F-1 with a range of –1.2 to –0.7‰ (0.5‰). The S604 and CDU plots had fluctuations of the $\delta^{15}N$ values that were wider, with a range of –0.5 to +1.7‰ (2.2‰) and –1.3 to +2.9‰ (4.2‰), respectively.

6. Element concentration of the tomato fruit

On the whole for nitrogen concentration of tomato fruit, higher nitrogen content was present in the chemical treatments than the organic treatment and fruit from higher trusses had lower nitrogen concentration (Table 2). For the organic fertilizer plots, nitrogen concentration of the CM+PM plot fruit on the first truss was lower with a con-

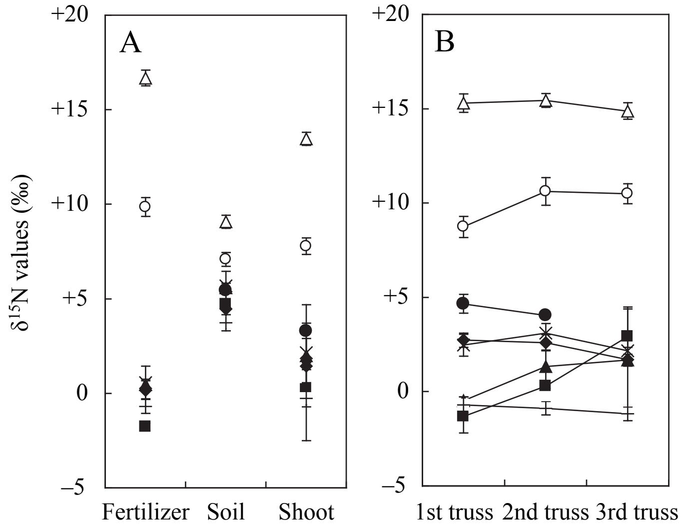

Fig. 5. Effects of different kinds of fertilizer and application methods on the $\delta^{15}N$ values of shoot and fruit
●: Control, ▲: S604, ■: CDU, ×: LSR, ◆: LP, +: OK-F-1, △: CM+PM, ○: PEL.
A: $\delta^{15}N$ Values of fertilizer, soil and shoot. B: $\delta^{15}N$ Values of fruits.
Vertical bars indicate SD of 3 samples except for 2nd truss of tomato control plot (n = 1) and 3rd truss of tomato CDU, LP and CM+PM plots (n = 2, 1, 2, respectively).

Table 2. Effects of different kinds of fertilizers and application methods on the inorganic content of tomato fruit

Treatment	Truss No.	N	P	K g kg^{-1}	Ca	Mg
Cont.	1	19.4 ± 8.4	4.28 ± 0.44	25.4 ± 1.5	1.15 ± 0.14	1.30 ± 0.04
	2	10.9 –	3.45 –	20.6 –	1.18 –	1.00 –
	3	–	–	–	–	–
S604	1	20.3 ± 0.6	3.44 ± 0.12	20.3 ± 0.8	0.82 ± 0.02	0.83 ± 0.07
	2	18.9 ± 1.2	3.38 ± 0.24	20.5 ± 0.8	0.68 ± 0.06	0.92 ± 0.08
	3	18.5 ± 0.9	3.27 ± 0.13	19.3 ± 0.4	0.45 ± 0.03	1.03 ± 0.08
CDU	1	19.9 ± 0.5	3.82 ± 0.14	22.9 ± 1.4	0.79 ± 0.08	0.94 ± 0.08
	2	17.3 ± 1.0	3.55 ± 0.19	20.6 ± 2.0	0.81 ± 0.14	0.98 ± 0.04
	3	11.8 ± 5.9	2.31 ± 1.17	12.3 ± 6.1	0.27 ± 0.14	0.68 ± 0.34
LSR	1	20.6 ± 2.5	3.89 ± 0.29	23.1 ± 1.9	1.39 ± 0.07	1.10 ± 0.07
	2	15.5 ± 0.4	3.86 ± 0.34	23.1 ± 0.7	1.36 ± 0.17	1.13 ± 0.06
	3	14.2 ± 0.8	3.70 ± 0.21	22.1 ± 0.3	0.95 ± 0.04	1.16 ± 0.04
LP	1	13.1 ± 0.7	3.74 ± 0.23	22.8 ± 1.4	1.22 ± 0.00	1.10 ± 0.06
	2	13.6 ± 0.5	3.78 ± 0.10	26.4 ± 0.7	1.12 ± 0.11	1.11 ± 0.03
	3	–	–	–	–	–
OK-F-1	1	18.9 ± 0.3	3.85 ± 0.07	23.4 ± 2.6	1.00 ± 0.09	0.97 ± 0.03
	2	17.9 ± 0.7	3.60 ± 0.09	23.0 ± 1.2	0.94 ± 0.04	0.92 ± 0.05
	3	15.7 ± 1.3	3.42 ± 0.03	21.2 ± 0.5	0.59 ± 0.05	1.08 ± 0.01
CM+PM	1	11.6 ± 0.9	4.17 ± 0.17	26.8 ± 1.3	0.88 ± 0.03	1.24 ± 0.06
	2	8.4 ± 0.8	3.47 ± 0.09	22.0 ± 0.2	1.40 ± 0.27	1.09 ± 0.01
	3	8.4 ± 4.3	2.29 ± 1.14	17.3 ± 8.7	1.35 ± 0.72	0.92 ± 0.46
PEL	1	17.7 ± 0.6	4.02 ± 0.08	23.6 ± 0.2	0.90 ± 0.04	1.08 ± 0.06
	2	13.3 ± 1.2	3.83 ± 0.17	22.0 ± 0.5	0.89 ± 0.14	1.11 ± 0.05
	3	11.4 ± 1.4	3.82 ± 0.14	23.1 ± 0.8	0.79 ± 0.13	1.09 ± 0.01

Average of 3 samples ±SD, –: not determined.

centration of 11.6 mg/g which was almost half of the ordinal tomato nitrogen concentration (20 mg/g). Moreover, these concentrations decreased to 8.4 mg/g on the second and third truss of the CM+PM plot. For the PEL plot, the concentration was lower than the chemical fertilizer plots.

The tendency for phosphate and potassium was different from nitrogen, even though in the organic fertilizer plots, these concentrations were kept relatively high. While the calcium concentration of S604, CDU and LSR plots of the higher truss fruits decreased, the concentrations of the CM+PM and PEL plots remained higher on the third truss. Magnesium concentration was almost the same among the treatments, whose concentration was constant at around 1.0 mg/g.

Discussion

1. Shoot and root growth

In the control plot (Cont.), both shoot and root growth was lowest among the treatments, LP and CM+PM plots followed the control plot, because their nutrient release was insufficient and less than the other plots. While both shoot and root growths were different among the plots, shoot growth was correlated with the root growth (R^2 = 0.89). However, the ratio of shoots and roots (S/R ratio) was different among the plots; roughly, the plots with lower shoot growth had a lower S/R ratio (Fig. 1). Shoot growth was more sensitively restricted by the root condition. For the S604 and CDU plot, though shoots were the same level of OK-F-1 plot, S/R ratio was not so high compared with OK-F-1 plot. For the case of the CDU plot, the high EC after cultivation (Fig. 3) meant more fertilized nutrient remained with relatively restricted shoot growth and a decreased S/R ratio. When CDU compound fertilizer was used excessively, extremely higher ion concentrations in the rhizosphere reduced shoot growth and the S/R ratio was also restricted[4]. For nutrient deficiency, excess and imbalance, as in other adverse conditions, transport of assimilate to the root is increased supposedly in order to resist the stress. From the results of Figs. 1 and 2, and assuming 95% water content of fruit, total upper parts (shoots and fruits) dry weight was determined and the OK-F-1 plot was heaviest among the treatments. In this plot, fertilizer was applied daily little by little, with higher efficiency of nutrient use accomplished than the other treatments did, which meant that lower ion stress (nutrient deficiency, excess and imbalance) to the roots occurred during the cultivation. For the OK-F-1 plot, even though the upper part weight was heaviest, root weight was relatively restricted with the highest S/R ratio among the treatments. There is the possibility of using the S/R ratio as an indicator of plant growth health. Such management strategies could lead to the achievement of maximum tomato yields.

2. Fruit yield and nutrient content and condition of the rhizosphere

For the LSR and PEL plots, stress in the rhizosphere was relatively low and soil conditions kept nutrients available. For the OK-F-1 plot, daily applied fertilizer made nutrient availability high, which resulted in a high yield of the third truss. While yields were the same among the LSR, OK-F-1 and PEL plots, there were differences in nutrient contents (Table 2). The widest variation was in nitrogen concentration compared with other nutrients, the OK-F-1 plot had high nitrogen content compared with the LSR and PEL plots, even in the second and third trusses. In general, the nitrogen content of fruit had a high correlation to amino acid (glutamate), with higher concentrations supposedly of higher quality. In considering both yield and quality, daily application of inorganic fertilizer was associated with higher tomato quality and yields than the other treatments.

On the other hand, for the LP and CM+PM plots, the third truss yield was quite low, from the results of soil extract of the 1:5 soil extract, nutrient availability in the LP and CM+PM plots were kept low. Especially for the LP plot, in which the half life of the fertilizer was 140 days, it was assumed that the nutrients released during the cultivation term was too low to meet the needs of tomato growth.

3. Nitrogen behavior and its effect on productivity of tomato

The $\delta^{15}N$ values of chemical fertilizer were around 0‰ which was from –1.8‰ to +0.6‰. On the other hand, the $\delta^{15}N$ values of organic fertilizer were higher than that of chemical fertilizer, in which manure pellets was +9.9‰ and the mixture of cattle and poultry manure was +16.7‰. These results were almost the same as previous results[6]. However, the $\delta^{15}N$ values of soil after cultivation were reflected in the $\delta^{15}N$ values of the fertilizer applied, the $\delta^{15}N$ values of the soils in every plot contracted to the $\delta^{15}N$ values of the soil itself which was +5.4‰; the value of soil without fertilization. These results showed that the amount of soil nitrogen was relatively higher compared with that of fertilizer and strongly affected the $\delta^{15}N$ value of the growth medium. That is, the average $\delta^{15}N$ value for soil nitrogen of +5.8‰ with a relatively narrow range which is close to the $\delta^{15}N$ values of the soil itself, differed from the $\delta^{15}N$ values of the plant which had a range of +3.7‰ to +9.1‰.

While for the organic fertilization, the $\delta^{15}N$ values of shoots and fruits were close to the $\delta^{15}N$ values of fertilizer, not to the values of soil. It is supposed the soil nitrogen was also absorbed and their values decreased to close to +5.4‰, the soil nitrogen $\delta^{15}N$ value. On the other hand, for the chemical fertilizer plot, the $\delta^{15}N$ values of shoots were higher than the $\delta^{15}N$ values of fertilizer, with the exception of the OK-F-1 plot, with $\delta^{15}N$ values of shoots only 0.4‰ higher than the $\delta^{15}N$ values of fertilizer. The $\delta^{15}N$ value of shoots was the same as that of the fertilizer applied. For the $\delta^{15}N$ values of fruit, chemical fertilizer plots had values below +3.1‰ and organic fertilizer plots had values over +8.7‰. The use of $\delta^{15}N$ values to differentiate between crops grown by organic and inorganic production systems was proposed, and its criterion was set around +4‰[7]. In this experiment, the results lead to the same conclusion, even when different fertilizers were used.

For organic fertilization, the fluctuation of $\delta^{15}N$ values of fruit among trusses was small, that is, the CM+PM plot range was +14.9 to +15.4‰ (0.5‰) and the PEL plot range was +8.7 to +10.6‰ (1.9‰). For the CM+PM plot, growth itself was restricted, the growth rate was kept low in the late term of cultivation and then nitrogen released from organic fertilizer was supplied constantly to the fruit. On the other hand, for the PEL plot, growth was kept higher and slow-release nutrients released higher amounts of nutrients than the CM+PM plot, even in the late term of cultivation, with relatively abundant amounts of nitrogen released from organic fertilizer and supplied constantly to the fruit. Chemical fertilizer plots were divided into two patterns. One pattern had constant $\delta^{15}N$ values among treatments with little fluctuation, in which $\delta^{15}N$ values of LSR and LP plots were totally high and kept within 1‰ among the different trusses. This is because the effect of slow-release was expressed by supplying the soil nitrogen to the fruit in a nitrogen mixture derived from fertilizer and soil that was absorbed constantly. Another pattern was an increase in the $\delta^{15}N$ value with higher trusses. There was a relatively higher $\delta^{15}N$ value fluctuation recognized in S604 and CDU plots, and on the higher trusses the $\delta^{15}N$ values increased with a range of more than 2.2‰. In the CDU compound fertilizer, CDU (cyclo-di-urea, slow release component) was the main component but also contained readily available ammonium nitrogen of 4.5% out of a total 12% nitrogen. This readily available nitrogen was absorbed and therefore $\delta^{15}N$ values of the first truss were similar to the $\delta^{15}N$ values of the fertilizer, which then increased because of the increase in the ratio of soil nitrogen. The absorption manner lead to an increase in $\delta^{15}N$ values on higher trusses. In the same manner, for the S604 plot, readily available nitrogen was absorbed at the first stage followed by the soil nitrogen contribution increasing relatively at the late cultivation stage. For the OK-F-1 plot, $\delta^{15}N$ values of fruit were contracted within the range from –1.2‰ to –0.7‰, which were almost the same values as that of the fertilizer applied. This result showed that nitrogen application, such as daily liquid fertilizer application, i.e. fertigation, minimized the effect of soil nitrogen to the plant and therefore this method is quite an effective nitrogen application method, which was supported by the results of $\delta^{15}N$ values.

A two source model using $\delta^{15}N$ values[8] estimated the fertilizer contribution ratio to the tomato upper parts (shoots and fruits). The symbol f_f was used to represent the nitrogen fraction of fertilizer to the tomato upper parts and f_s was used to represent the nitrogen fraction of the soil nitrogen part. If only two sources were supposed to contribute to nitrogen content of tomato upper parts, the equation can be expressed as $f_f + f_s = 1$ (Eq. 1). The $\delta^{15}N$ values of fertilizer nitrogen, soil nitrogen and then upper parts of tomato were represented by δ_f, δ_s and δ_p, respectively, with the equation $\delta_p = f_f\delta_f + f_s\delta_s$ (Eq. 2). Eq. 2 was substituted by Eq. 1, then the contribution ratio of fertilizer nitrogen of the tomato upper parts was described as $f_f = (\delta_p - \delta_s)/(\delta_f - \delta_s)$ (Eq. 3). By this equation, the contribution ratio of each different fertilizer to the nitrogen of the upper parts of tomato was estimated. In Eq. 3, average $\delta^{15}N$ values of the upper parts of the whole tomato was calculated on the supposition that fruit water content was 95% using the fruit fresh weight of Fig. 2 and shoot dry matter weight of Fig. 1 with $\delta^{15}N$ values of fruit and shoot on Fig. 5. These $\delta^{15}N$ values of fertilizer (Table 1) and that of the soil (+5.4‰) were used to evaluate the contribution of fertilizer to the tomato upper parts in Eq. 3.

These results showed the S604 and CDU plots which included relatively high contents of readily available nitrogen, contributed 80% and 75% of nitrogen of the tomato, respectively. The LSR and LP plots which had relatively slow-release contributed 62% and 64% respectively, which was lower than the former two fertilizers. For the organic fertilizer, the CM+PM and PEL plots contributed 79% and 73% respectively, which was higher than slow release fertilizer. The highest contribution was observed in the OK-F-1 plot, contributing 96% of nitrogen in the upper parts, which meant that little nitrogen was supposedly absorbed from the soil and nitrogen was effectively used for the tomato growth with fertigation.

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