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Real-Time Diagnosis of Soil Solution of Cucumber in Protected Cultivation Using Compact Nitrate Ion-Meter

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Abstract

To develop a technique for efficiently managing fertilizer application for cucumbers in protected cultivation, real-time diagnosis of the soil solution was examined by using simple instruments to obtain the nitrate content of the soil solution as an indicator. As a result, since the value of the nitrate content measured in the soil solution using a compact nitrate ion-meter was comparable to the value measured by the phenolsulfuric acid method, it became possible to use a compact nitrate ion-meter to measure the nitrate content of the soil solution in the field. Also, based on the relation between the nitrate content of the soil solution and the yield of cucumber fruit, to secure stable production, the nitrate content in the soil solution should range from 400 to 800 mg·L^{-1} during the harvest period for semi-forcing and retarding cultures.

Discipline: Soils, fertilizers and plant nutrition
Additional key words: semi-forcing culture, retarding culture

Introduction

Most of the fruit vegetables are cultivated in greenhouses, where they are subjected to the application of large amounts of fertilizers and there is no leaching of nutrients from natural rainfall. The combination of these effects leads to the accumulation of nutrients over the optimum quantity in the soil. Therefore, during the cultivation period, accurate management of fertilization requires that the soil nutrients be maintained appropriately.

For accurate management of fertilization, it is essential to develop methods for real-time soil diagnosis to determine the nutrient conditions of soil in the field and to apply fertilizers when necessary.

Recently, kits for measuring the nitrate content in soil as well as tools for collecting the soil solution have been developed and are available commercially[2] for use during the cultivation period. Then, by determing the standard value of nitrate for accurate management of fertilization, fertilizer can be applied efficiently, based on real-time soil diagnosis. In the present study, for cucumbers in protected cultivation, the nitrate content in the soil solution of plots with a different quantity of nitrogen was measured for real-time diagnosis. Based on the relation between the nitrate content in the soil solution and the cucumber yield, the nitrate content in the soil solution required to achieve stable production was determined.

Experimental methods

1) *Outline of cultivation, design of experimental plots*

Tests on cucumbers in semi-forcing or retarding culture were carried out in a greenhouse of Saitama Horticulture Experiment Station in 1993. Cucumbers were planted on February 16 for semi-forcing culture and August 30 for retarding culture. To control the growth, the primary scaffold branch was pinched back at the 21st node and the lateral branch at the 3rd node, and from the time of planting to the end of harvest, the plants were irrigated at intervals of 10 days. For semi-forcing culture, heaters were used from the time of planting in February to May, and minimum night-time temperatures were maintained at above 13°C. For both semi-forcing and retarding cultures, the top ventilator was opened whenever the temperatures inside the house reached 28°C. Harvest in semi-forcing culture was started on April 1. The harvest period lasted for 90 days from April to June. Harvest in retarding culture started in September 30 and the harvest period lasted for 60 days from October to November.

The test plots consisted of a standard plot, a plot with nitrogen application 0.5 times that of the standard plot (hereafter referred to as N 0.5 plot), a plot with nitrogen application 1.5 times that of the standard plot (hereafter referred to as N 1.5 plot), and, to simplify topdressing, a plot with coated fertilizer nitrogen of 140-day type (hereafter referred to as CFN plot) and compound fertilizer as basal application.

Topdressing on the standard plot, N 0.5 plot, N 1.5 plot was carried out 4 times at intervals of 3 weeks after the beginning of harvest in semi-forcing culture, 3 times at intervals of 3 weeks after the beginning of harvest in retarding culture.

Topdressing in semi-forcing culture was conducted on April 1, April 21, May 10, June 1, and in retarding culture on October 1, October 20, November 10. Also, the quantity of nitrogen or potassium used for each topdressing in semi-forcing culture was 50 $kg \cdot ha^{-1}$ and in retarding culture 33–34 $kg \cdot ha^{-1}$.

The design of the test plots is shown in Table 1 and the schedule of cultivation is given in Table 2.

2) Collection of soil solution

For the collection of the soil solution, a device with a porous cap and a collector was used. The section with the porous cap was buried at a fixed depth, and when the soil solution was sampled, a vacuum was created in the collection device to obtain the soil solution (Plate 1).

For both semi-forcing and retarding cultures, the

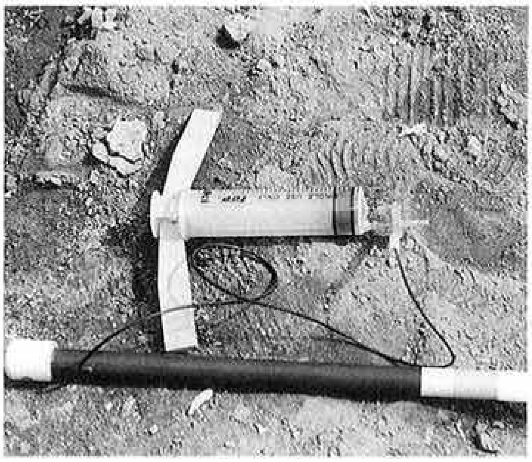

Plate 1. Tool for the collection of the soil solution

Table 1. Design of experimental plot

($kg \cdot ha^{-1}$)

Experimental plot	Semi-forcing culture			Retarding culture		
	$N \cdot K_2O$		P_2O_5	$N \cdot K_2O$		P_2O_5
	Basal application	Topdressing	Basal application	Basal application	Topdressing	Basal application
Standard plot	200	200	400	100	100	200
N 0.5 plot	100	100	400	50	50	200
N 1.5 plot	300	300	400	150	150	200
Coated fertilizer plot	400	–	400	–	–	–

Note: The nitrogen amount from coated fertilizer in the coated fertilizer plot was 280 $kg \cdot ha^{-1}$.
In the standard plot, N 0.5 plot and N 1.5 plot, for basal application, compound fertilizer (N-P_2O_5-K_2O, 13-13-13%) and superphosphate were used; for topdressing, ammonium sulfate and potassium sulfate were used.
The area of the experimental plot was 10.5 m^2 and the experiment was replicated twice.

Table 2. Outline of cultivation

Head	Semi-forcing culture	Retarding culture
Soil type	Brown Lowland soil	Brown Lowland soil
Budwood cultivar	Shāpu 1	Kifujin nyū taipu
Rootstock	Urutora kabocha	Urutora kabocha
Seeding	January 22	August 9
Grafting	February 2	August 16
Planting	February 16	August 30
Planting density	21,000 stocks per ha	21,000 stocks per ha

soil solution was collected at a depth of 15 cm for 1 to 2 days after irrigation, at intervals of 10 days. The nitrate content of the soil solution was measured by the phenol sulfuric acid method. At the same time, for real-time diagnosis, the nitrate content was determined with a compact nitrate ion-meter.

3) Preparation of petiole juice of cucumber

Within 2 to 3 days after the collection of the soil solution, the petioles from the 14th through 16th nodes in cucumber true leaf were collected and cut into sections approximately 2 cm long. These were then pressed with a garlic press to obtain the petiole juice, and the nitrate content in the juice was measured using the phenol sulfuric acid method.

Results and discussion

1) Conditions for collection of soil solution and simple method to measure the nitrate content

In order to determine the conditions for the collection of the soil solution, the porous cap was inserted at positions 5, 10, 15, and 20 cm from the surface layer and the nitrate content increased with the proximity to the surface layer (Table 3). Taking into consideration both the root zone and the position where the soil solution can be readily collected, it was considered that collection at a depth of 15 cm from the surface layer was the most appropriate. The soil solution per plot should be collected from 3 positions to avoid sampling errors (Table 4).

Table 3. Nitrate content of soil solution at each depth ($mg \cdot L^{-1}$)

5 cm	10 cm	15 cm	20 cm
2,170 (1,442)	1,710 (322)	1,320 (287)	1,090 (259)

Note: ( ) indicates standard deviation.
The soil solution was collected in the nitrate standard plot from March 3 to March 17. Nitrate content in Table 3 is the average value in 5 zones at each depth.
The nitrate content was measured with a compact nitrate ion-meter.

Also, 3 or 4 days after irrigation, the soil pF reaches a value of more than 1.8 and it is no longer possible to collect the soil solution using a porous cup, while the soil pF decreases below 1.2 immediately after irrigation. It was therefore considered that the optimum time for the collection of the soil solution was 1 to 2 days after irrigation when the soil pF was in the range of 1.6–1.8.

Measured values using a compact nitrate ion-meter, which is a convenient method to measure the nitrate content of the soil solution, were compared with measured values using the phenol sulfuric acid method. A significant correlation was observed between the 2 methods (Fig. 1, Plate 2). The use of the compact nitrate ion-meter was found to be a simple and convenient method of measurement. The kit used measures the test solution that drips down from above a nitrate electrode, after correction with the calibration fluid. Measurements require 2 to 3 min.

2) Yield of cucumber fruit and nitrate content in soil solution

The yield of cucumber in the standard plot in semi-forcing culture was constant each month from April in the early harvest period to June in the late harvest period, the total yield being 142 $t \cdot ha^{-1}$. In the N 1.5 plot, the yield was 98% of that in the standard plot, against 76% in the N 0.5 plot. The yield was 95% in the coated fertilizer plot. In the retarding culture, in the standard plot and N 1.5 plot an identical yield of 57 $t \cdot ha^{-1}$, was recorded while in the N 0.5 plot, the yield was 93% that of the standard plot (Tables 5 and 6).

The nitrate content of the soil solution in the standard plot in the semi-forcing culture remained in the range of 500 to 1,000 $mg \cdot L^{-1}$, while in the N 1.5 plot, it ranged between 2,000 and 2,500 $mg \cdot L^{-1}$ from April 7 to May 28. In all the periods the content was 2 to 3 times higher than in the standard plot. In the N 0.5 plot the nitrate content was low in the early harvest period of

Table 4. Nitrate content of soil solution in each collection zone at a depth of 15 cm ($mg \cdot L^{-1}$)

Experimental plot	1	2	3	4	5	6	7	8	9	Average	Standard deviation
Standard plot	1,700	990	2,200	590	1,300	860	1,900	990	1,400	1,330	497
N 0.5 plot	530	320	260	850	290	580	260	330	420	470	185

Note: The soil solution was collected from March 3 to March 10.
Nitrate content was measured with a compact nitrate ion-meter.

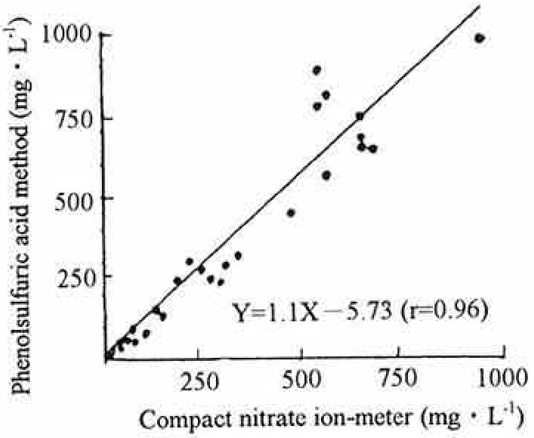

Fig. 1. Correlation between nitrate content in soil solution measured with a compact nitrate ion-meter and the phenolsulfuric acid method

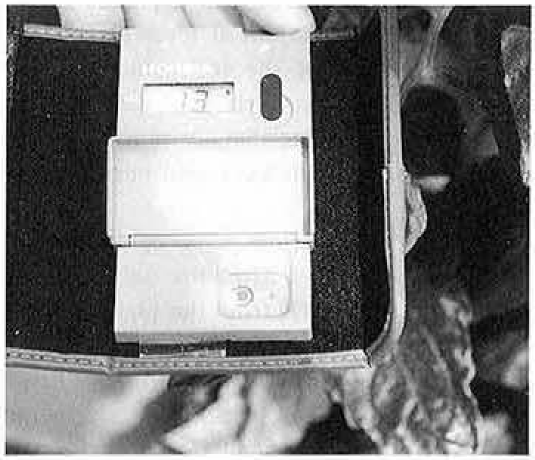

Plate 2. Compact nitrate ion-meter

April, and after May 19 the content was below 50 mg·L^{-1}. In the coated fertilizer plot the content was the same as in the standard plot until April 17, but after May 19 it remained below 100 mg·L^{-1} (Table 7).

The nitrate content of the soil solution in the retarding culture was around 500 mg·L^{-1} in all the harvest periods from October to November in the standard plot. In the N 0.5 plot it was below 100 mg·L^{-1}, and in the N 1.5 plot it was in the range of 1,200–1,300 mg·L^{-1} from October 7 to November 5, and 800 mg·L^{-1} on November 26. In all the periods, the nitrate content of the soil solution in the N 1.5 plot was 2 to 3 times higher than that in the standard plot (Table 7).

Also, in the case of topdressing, since the nitrate content of the soil solution was similar to that before topdressing, it was assumed that ammonium nitrogen in the fertilizer remained in the surface layer.

As for the yield and nitrate content in the soil solution, in both the semi-forcing and retarding cultures, the yield was low in the N 0.5 plot due to the lack of nitrogen. In the 1.5 plot, the yield was similar to that in the standard plot, although the nitrate content was consistently 2 to 3 times higher than in the standard plot. Based on these findings, it was considered that there was an excess of nitrogen in the N 1.5 plot. Also, in the coated fertilizer plot in the semi-forcing culture, the nitrate content decreased from May 8 with a concomitant decrease

Table 5. Yield of cucumber fruit in semi-forcing culture

(t·ha^{-1})

Experimental plot	April		May		June		Yield index of good quality per standard plot
	Good quality	Poor quality	Good quality	Poor quality	Good quality	Poor quality	
Standard plot	45.6	4.9	50.8	12.7	45.1	12.2	100
N 0.5 plot	38.9	5.3	38.2	13.7	30.9	16.7	76
N 1.5 plot	48.3	6.2	48.5	13.5	42.0	12.1	98
Coated fertilizer plot	48.5	5.3	47.4	12.3	38.2	14.9	95

Table 6. Yield of cucumber fruit in retarding culture

(t·ha^{-1})

Experimental plot	October		November		Yield index of good quality per standard plot
	Good quality	Poor quality	Good quality	Poor quality	
Standard plot	38.8	2.8	18.0	1.7	100
N 0.5 plot	33.4	1.3	19.5	1.3	93
N 1.5 plot	35.8	2.5	21.1	1.7	100

Table 7. Nitrate content in soil solution

($mg \cdot L^{-1}$)

Experimental plot	Semi-forcing culture								Retarding culture					
	Mar. 25	Apr. 7	Apr. 17	Apr. 28	May 8	May 19	May 28	June 9	Oct. 7	Oct. 16	Oct. 28	Nov. 5	Nov. 16	Nov. 26
Standard plot	1,027	787*	732	620*	867	928*	850	504*	477*	395	413*	535	450*	566
N 0.5 plot	345	154*	48	12*	195	50*	28	13*	97*	50	96*	49	77*	55
N 1.5 plot	1,889	2,176*	2,500	2,358*	2,531	2,462*	2,200	1,331*	1,238*	1,230	1,436*	1,251	898*	800
Coated fertilizer plot	805	566	500	322	150	82	100	22	–	–	–	–	–	–

Note: The soil solution was collected at a depth of 15 cm.
The nitrate content was measured by the phenolsulfuric acid method.
The sign * indicates that topdressing was applied before the collection of the soil solution.

Table 8. Nitrate content in petiole juice

($mg \cdot L^{-1}$)

Experimental plot	Semi-forcing culture								Retarding culture					
	Mar. 26	Apr. 8	Apr. 20	Apr. 30	May 8	May 20	May 29	June 10	Oct. 8	Oct. 19	Oct. 29	Nov. 6	Nov. 17	Nov. 26
Standard plot	5,130	3,890*	2,800	2,120*	1,710	1,410*	750	490*	2,450*	3,100	3,400*	3,100	2,620*	2,800
N 0.5 plot	3,270	2,210*	840	300*	250	380*	320	150*	770*	1,200	1,160*	430	10*	10
N 1.5 plot	5,820	5,600*	4,800	3,980*	3,130	3,210*	2,690	1,390*	3,520*	4,750	4,930*	5,840	5,900*	6,260
Coated fertilizer plot	4,890	3,850	2,000	1,620	190	200	160	60	–	–	–	–	–	–

Note: Petiole juice was collected from the 14th through the 16th nodes in cucumber true leaf.
The nitrate content was measured by the phenolsulfuric acid method.
The sign * indicates that topdressing was applied before the collection of the soil solution.

in yield. This phenomenon was attributed to the fact that the amount of nitrogen eluted from the coated fertilizer used in basal application, was lower than the nitrogen required for the fruit growth.

The yield decreased when the nitrate content in the soil solution corresponded to the level in the N 0.5 plot. Since the yield does not increase at the level corresponding to that in the N 1.5 plot, the nitrate content corresponding to the level of the standard plot is considered to be optimal for achieving stable production.

3) Nitrate content in petiole juice

The nitrate content of the petiole juice in semi-forcing culture was 4,000 – 5,000 $mg \cdot L^{-1}$ from March 26 to April 8 in the standard plot, but it decreased in the late harvest period, and was 500 – 1,400 $mg \cdot L^{-1}$ from May 20 to June 10. In the N 1.5 plot, the nitrate content was high throughout the harvest period, and after May 20 it was 2 to 3 times that in the standard plot. There was a rapid decrease in the nitrate content from April 20 in the N 0.5 plot, and from May 8 in the coated fertilizer plot, and it remained at around 200 $mg \cdot L^{-1}$ until the end of harvest (Table 8).

In the retarding culture, the nitrate content was around 3,000 $mg \cdot L^{-1}$ in the standard plot during the harvest period. In the N 1.5 plot it was 3,500 – 5,000 $mg \cdot L^{-1}$ in the early harvest period of October, and around 6,000 $mg \cdot L^{-1}$ in November. As with the semi-forcing culture, the content remained higher than in the standard plot. In the N 0.5 plot, the content was around 1,000 $mg \cdot L^{-1}$ in October, but below 500 $mg \cdot L^{-1}$ in November (Table 8).

Since crops grow by absorbing nutrients in soil, there is a close relation between the content of soil nutrients and that of crop nutrients. Therefore in this study, the relation of the nitrate content between the soil solution and petiole juice was investigated in the semi-forcing culture or retarding culture.

In the semi-forcing culture, as the nitrate content of the petiole juice decreased in the late harvest period, the relation was studied for 4 periods as follows: April 7 – 8, April 28 – 30, May 8 and May 28 – 29.

As a result, in the semi-forcing culture, there was a significant correlation between the content in the soil solution and petiole juice in the April 7 – 8, April 28 – 30, May 8, and May 28 – 29 periods (Fig. 2). The correlation in the retarding culture was also significant but less than in the semi-forcing culture

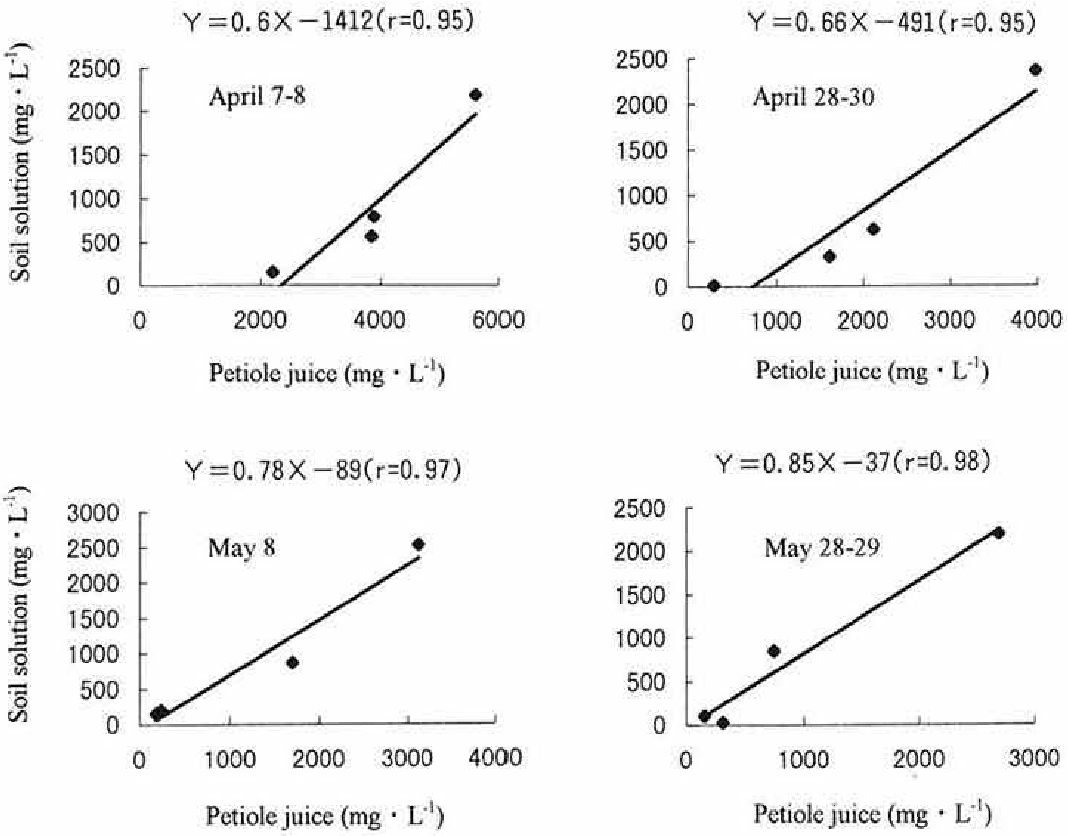

Fig. 2. Correlation of nitrate content between the soil solution and petiole juice in semi-forcing culture

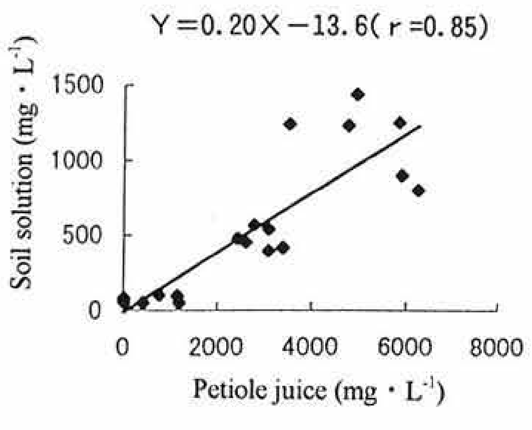

Fig. 3. Correlation of nitrate content between the soil solution and petiole juice in retarding culture

(Fig. 3). The nitrate content in the soil solution exerted a considerable effect on the nitrate content of the petiole juice.

4) Fertilizer control method for stable production

With real-time diagnosis, the soil and crop nutrient levels measured during the cultivation period are useful for the later fertilization management. As a result, this analysis is particularly suitable for fruit vegetables with a long growing season. At present, standard diagnostic values of nitrate and phosphorus in the petiole juice as indicators can be applied for cucumbers[4,9], tomatoes[7], strawberries[5], and eggplants[6], but for the soil solution such standard values can be applied for roses only[1]. There have been far fewer soil diagnosis studies compared to those for nutrient diagnosis.

Results from the present experiment indicate the presence of a constant correlation between the nitrate content of the soil solution and yield. Maintaining the nitrate content at 500–1,000 $mg \cdot L^{-1}$ in semi-forcing culture and at 400–500 $mg \cdot L^{-1}$ in retarding culture ensures stable production without the accumulation of excess nitrogen in the soil. Also as shown in Figs. 2 and 3, a nitrate content of 500–700 $mg \cdot L^{-1}$ in the soil solution matches the standard values of nutrient diagnosis in semi-forcing and retarding cultures. Therefore, the diagnostic standard values for the nitrate content in the soil solution during the harvest period in semi-forcing and retarding cultures can be set at 400–800 $mg \cdot L^{-1}$. Measuring the nitrate content with simple instruments is necessary for real-time diagnosis. In addition to the compact nitrate ion-meter, the suitability of merckoquant nitrate test paper[4,8], and of a measuring system combining a reflection photometer and test paper[3] has also been confirmed.

In this method of real-time diagnosis of the soil solution, the soil solution can be collected by creating a vacuum in the solution collector on the day before the measurement. On the next day, the nitrate content of the soil solution in the collection device is measured, and if the levels are higher than the diagnostic standard values, the amount of topdressing can be reduced until the next measurement. If within the range of standard values, normal fertilizer application is continued, and if the nitrate content is low, topdressing should be applied immediately, to secure appropriate fertilizer management.

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