Contribution of N Derived from a Hairy Vetch Incorporated in the Previous Year to Tomato N Uptake under Hairy Vetch-tomato Rotational Cropping System

Yuichi Sugihara1, Hideto Ueno2, Toshiyuki Hirata3, Masakazu Komatsuzaki4 and Hajime Araki3*

1Graduate School of Environmental Science, Hokkaido University, Sapporo 060-0810, Japan
2Faculty of Agriculture, Ehime University, Matsuyama 799-2424, Japan
3Field Science Center for Northern Biosphere, Hokkaido University, Sapporo 060-0811, Japan
4College of Agriculture, Ibaraki University, Ami, Ibaraki 300-0393, Japan

Utilization of cover crops helps the establishment of environmentally friendly agriculture due to their nutrition supplying ability mainly in the current year of application, but cover crop-derived N also remains until the following year. In the present study, the nutritional effect of a cover crop on tomato production in a greenhouse in the following year was investigated using the 15N-labeling method. Hairy vetch (Vicia villosa R., HV) was used as a cover crop. 15N-labeled HV (1319 mg N/pot) was applied to a 1/2000 a Wagner pot, and a fresh market tomato (Solanum lycopersicum L., ‘House Momotaro’ was cultivated in it at 0, 80, and 240 kg·ha⁻¹ of N application in 2011 (N₀HV, N₈₀HV, and N₂₄₀HV). After the tomato cultivation in 2011, the soil was stored in a greenhouse (the temperature varied from −4.1°C to 26.5°C) without any water or fertilizer. Tomatoes were cultivated again in the Wagner pots containing the soil used in 2011, to which was added the same rate of N fertilizer (0, 80, and 240 kg·ha⁻¹ of N) and unlabeled HV (935 mg N/pot) in 2012. Total N uptake of tomato plants was higher in N₂₄₀HV (2377 mg/plant), followed by N₈₀HV (1760 mg/plant), N₀HV (1498 mg/plant). On the other hand, the uptake of N derived from HV applied in 2011 (HV₂₀₁₁, 1319 mg N/pot) was not different among the treatments (57.7 mg/plant on average); thus, nitrogen use efficiency derived from HV₂₀₁₁⁻N in 2012 was 4.4% on average. This value was much lower than that in 2011 (47.1% on average), but HV₂₀₁₁⁻N also remained in the soil after the tomato cultivation in 2012 (500 mg N/pot). The distribution ratios of HV₂₀₁₁⁻N to the fruit in 1st and 2nd fruit clusters that developed in the early growth period were higher than those of N derived from soil, fertilizer, and HV applied in 2012. These results showed that although the N supplying effect of HV was small, HV could be available not only as short-term N source, but also long-term N source, and HV-derived N applied in the previous year was absorbed by tomato plants during a relatively early growth period in the following year.

Key Words: 15N, N use efficiency.

Introduction

The reduction of chemical fertilizer application is required for an environmentally friendly cropping system, and cover crops play a part in the establishment of the reducing fertilizer management. Cover crops are planted to enhance soil fertility and quality, and to increase the yield of the following cash crop (Acosta et al., 2011). The examples of cover crop effects are stabilizing soil temperature (Araki and Ito, 1998; Hoyt and Hargrove, 1986; Teasdale and Abdul-Baki, 1995), reducing soil erosion (Langdale et al., 1991), improving soil physical properties (Blevins and Frye, 1993), increasing soil fertility (Araki et al., 2009; Cavigelli and Thien, 2003), and suppressing weeds (Creamer et al., 1996; Teasdale, 1993). The most important role of cover crops as the alternative of chemical fertilizers is the utilization as nutrient management tools (Ruffo and...
Hairy vetch (Vicia villosa; HV), a legume crop, is superior in terms of N supplying capacity due to its efficiency in biological nitrogen fixation (Acosta et al., 2011; Seo et al., 2006). HV has also other advantages such as adaptability at low temperature, resistance to pests, delayed senescence, covering ground surface effectively, and fitness for vegetable production, particularly in rotation with tomatoes (Kumar et al., 2005).

The nutrition supplying capacity of cover crops varies with cover crop species, subsequent crop species, environmental circumstances, and applying methods. In tomato production with cover crops, Thönissen et al. (2000) reported that when legumes were incorporated or mulched into the soil, tomatoes absorbed 8.9% or 9.6% of soybean-derived N and 10.0% or 15.0% of indigofera-derived N, respectively. In another report, the higher recovery rate of cover crop-derived N was also reported; 56% of HV-derived N was recovered by rice (Asagi and Ueno, 2009). The $^{15}$N-labeling method was used in evaluation of N recovery from cover crops in these reports. This method is suitable for the investigation of crop N uptake derived from cover crops, because it is possible to conduct a direct investigation of N dynamics.

In most reports, however, cover crop-derived N recovery rates are often less than 50%, and more than half of cover crop-derived N remains in soil, or leaches into deep layers of soil, without absorption by subsequent crops. Cover crop-derived N is more likely to be recovered in soil organic N than N derived from inorganic fertilizer (Harris et al., 1994; Seo et al., 2006; Varco et al., 1993). Thus, the nutrition supplying capacity of cover crops may occur not only in the current year, but also in the following year. Some studies have reported that the recovery rate of N derived from HV applied in the previous year was from 2.3% to 3.8% in maize and oats. (Acosta et al., 2011; Cueto-Wong et al., 2001; Seo et al., 2006).

As intensive tomato production in greenhouse needs a large amount of nutrition for the healthy growth and sufficient yield, the utilization of cover crops is desired to achieve a cropping system with reduction of fertilizer. Araki et al. (2009) could reduce by 50% the recommended chemical N fertilizer application using HV as a cover crop without any reduction of fruit yield in tomato production. Our previous study showed that the N supplying effect of HV was concentrated in the early tomato growth period, and tomatoes absorbed the N derived from HV more efficiency by reducing chemical N fertilizer; about 50% of N derived from HV was recovered by tomato plants (Sugihara et al., 2013). However, there are few reports about the N supplying effect of HV in intensive tomato production in the following year. Since the same crops are liable to be cultivated continuously without an intensive tillage in a protected horticulture, the nutrition more readily accumulates than in a field cultivation. Thus, it is important to investigate the nutritional effect of HV in the following year in the tomato production in a greenhouse.

The objective of the present study was to assess the following year’s effect of HV as a cover crop on the tomato growth and N uptake, in order to understand the complex N dynamics in HV-used tomato cultivation, and to obtain fundamental data on the introduction of a cover crop to maintain the continuous productivity of the soil in intensive soil culture in the greenhouse.

**Materials and Methods**

This experiment was conducted at the Experimental Farm, Field Science Center for Northern Biosphere, Hokkaido University, Sapporo, Japan, without unlabeled HV cultivation which was conducted at the experimental field at Ibaraki University in 2012.

**Soil preparation and experimental design**

In our previous study, the tomato cultivation experiment with $^{15}$N-labeled HV (0.86 atom% excess, 1319 mg N/pot) in a 1/2000 a Wagner pot containing 10 kg Andisol soil in the experimental farm (C and N concentrations were 3.82% and 0.30%, respectively) was conducted in 2011 (Sugihara et al., 2013) (Fig. 1; Table 1). That experiment was carried out at three N fertilizer application rates, 0 kg N·ha$^{-1}$ (0 mg N/pot, N0HV), 80 kg N·ha$^{-1}$ (400 mg N/pot, N80HV), and 240 kg N·ha$^{-1}$ (1200 mg N/pot, N240HV), and was replicated 5 pots in each treatment. The cultivation in the previous year was conducted almost in the same way in 2012, as described later. Detail cultivation methods and history were described in the previous study (Sugihara et al., 2013). After the end of cultivation on September 218, Y. Sugihara, H. Ueno, T. Hirata, M. Komatsuzaki and H. Araki
1, 2011, the soil used for the experiment was left in each pot, and was covered with film, and kept in a greenhouse until June 8, 2012. During the storage period, no water or fertilizer was added to the pots. The temperature inside the greenhouse varied from −4.1°C (night) to 26.5°C (day) in winter because forcing culture of asparagus was performed in the same greenhouse. On June 8, 2012, the used soil of 5 pots were gathered into the one container in each treatment once, well mixed, and then, redistributed into 5 pots again in each treatment. These used soil contained 15N-labeled HV residues.

In the present study, 2012, three N fertilizer application rates with five replications the same as in the previous study were prepared, in that, 0 kg N·ha−1, 80 kg N·ha−1, and 240 kg N·ha−1 (0 mg N/pot, 400 mg N/pot, and 1200 mg N/pot) were applied to the soil used as N0HV, N80HV, and N240HV treatment in the previous study, respectively (Fig. 1). And then, three rates of N chemical fertilizer, 0 kg N·ha−1, 80 kg N·ha−1, and 240 kg N·ha−1 (0 mg N/pot, 400 mg N/pot, and 1200 mg N/pot) were applied to the soil used as N0HV, N80HV, and N240HV treatment in the previous study, respectively. Applied chemical N fertilizer contained 20% of fast-release (Ammonium sulfate; JFE Chemical Corporation, Tokyo, Japan) and 80% of slow-release (LPS100 40%-N; JCAM AGRI. Co., Ltd., Tokyo, Japan). In every plot, 200 kg P2O5 by fused magnesium phosphate (Hinode Chemical Industry Co., Ltd., Kyoto, Japan) and 200 kg K2O by potassium sulfate (Hokuren Nogyo Kyodo Kumiai, Hokkaido, Japan) were added per ha. Irrigation was conducted so as not to dry the soil surface, and the water flowed under the pot. Mean soil temperature during the cultivation period was 24.3°C (highest: 40.3°C, lowest: 12.8°C), and soil water tension changed from pF 1.6 to pF 2.5 during the experiment. Weeds were removed by hand. Pesticides and fungicides were applied 4 times. The solution of tomato-tone (Ishihara Sangyo Co. Ltd., Osaka, Japan), which was diluted 100 times, was sprayed on flower for stable fruiting when more than 3 flowers came into bloom in every flower cluster. Tomato-tone is one of the commercial plant growth regulators that accelerates the fruiting and enlargement in Solanaceae and Cucurbitaceae vegetables, and contains 1500 ppm 4-chlorophenoxyacetic acid. Only 3 fruits were allowed to set in each fruit cluster.

**Sample collection**

Five whole tomato plants without fruits were collected on September 3, 2012, and then separated into leaves, stems, and roots. Furthermore, the leaves and stems were separated into 4 parts under the 2nd fruit cluster (FC), 2nd–4th FC, 4th–6th FC, and upper 6th FC. Mature tomato fruits were harvested at appropriate times. Immature fruits were also harvested on

---

**Table 1.** C and N concentrations, isotope ratio, amount of dry weight, and N content of hairy vetch (HV).

| Organ | C (%) | N (%) | Atom% excess | Dry weight (g/pot) | N content (mg/pot) | Rate of shoots or roots N to total N (%) |
|-------|-------|-------|--------------|-------------------|-------------------|----------------------------------------|
| 2011 (previous study) | | | | | | |
| Shoots | 38.7 | 4.3 | 0.89 | 28.5 | 1211.7 | 91.9 |
| Roots | 37.0 | 2.1 | 0.56 | 5.0 | 107.1 | 8.1 |
| Total | 38.4 | 3.9 | 0.86 | 33.5 | 1318.8 | — |
| 2012 (present study) | | | | | | |
| Shoots | 41.7 | 3.7 | — | 25.0 | 935.2 | — |

* Isotopic ratio of total HV was calculated from the ratio of N content of shoots and roots.

† Unlabeled HV.
September 3, 2012. The soil was sampled 2 times, before and after tomato cultivation. The former was sampled on June 8, 2012, during the soil preparation, and the latter on September 3, 2012, after whole plants were collected.

**Chemical analysis**

After measuring the fresh weight of tomato fruits, the fruits and other parts were dried in a circulation oven at 90°C and 60°C for 4 and 2 days, respectively. DW of tomato plants was measured, and the dried samples were ground finely. Soil samples were also dried at 60°C and sieved through a 2-mm mesh. Total N concentration and the abundance of $^{15}$N in the powdered samples of the plants and soils were determined using an elemental analyzer (EA1110; Thermo Fisher Scientific Inc., Waltham, MA, USA) coupled to a Finnigan MAT252 isotope ratio mass spectrometer via a Con Flo 2 split interface (Thermo Fisher Scientific Inc.).

**Calculation**

The rate of plant N uptake derived from HV$_{2011}$ to total N uptake in tomato plants in 2012 ($\%$N$_{2011}$) can be calculated from Eq. (1).

$$\%$N$_{2011} = \frac{\text{atom } {^{15}}\text{N excess of tomato}}{\text{atom } {^{15}}\text{N excess of HV}_{2011}} \times 100 \quad (1)$$

The N use efficiency (NUE) derived from HV$_{2011}$, which is the recovery rate of N by tomato in 2012 from the applied N in HV$_{2011}$ can be calculated from Eq. (2).

$$\text{NUE} \text{%} = \frac{\text{Tomato N uptake derived from HV}_{2011} \text{ in 2012}}{\text{Amount of N applied in HV}_{2011}} \times 100 \quad (2)$$

The uptake amount of N derived from soil, fertilizer, and HV$_{2012}$ (unlabeled) can be calculated from Eq. (3).

$$\text{The uptake amount of N derived from soil, fertilizer, and HV}_{2012} \text{ (mg)} = \text{total N uptake by tomato} - \text{tomato N uptake derived from HV}_{2011} \text{ in 2012} \quad (3)$$

Through such calculation, N dynamics of HV applied in 2011 was evaluated: absorbance by tomatoes, remaining in the pot soil, leaching, and deminification.

**Statistical analysis**

Data were analyzed by one-way ANOVA, and significant differences of the mean values were calculated using the Tukey’s method, except when comparing two parameters, which were calculated using t-test. The value represents the mean of five replications.

**Results**

**Fruit yield and plant dry weight of tomato**

There was no significant difference in tomato fresh yield among the treatments (631 g/plant on average) (Table 2). However, the yield in 2012 was 40% less than that in 2011, 1040 g/plant on average. Plant DW varied significantly among the treatments; N240HV (168 g/plant) was the highest, followed by N80HV (149 g/plant), and N0HV (138 g/plant).

**Nitrogen uptake**

Total N content rate of tomato plants increased with N fertilizer; the total N uptake was also the highest in N240HV (2377 mg/plant), followed by N80HV (1760 mg/plant), and N0HV (1498 mg/plant) (Table 2). On the other hand, the N uptake derived from HV$_{2011}$ was not different among the treatments (57.7 mg/plant on average). Therefore, NUE derived from HV$_{2011}$ was also not different (4.4% on average). Although there

---

**Table 2.** Effect of HV applied in 2011 and N fertilizer applied in 2012 on the tomato fruit yield, whole plant’s dry weight, and N uptake.

| Treatments | 2012 | 2011 (Reference)* |
|------------|------|-------------------|
|            | Fruit fresh yield (g/plant) | Whole plant’s dry weight (g/plant) | Total N content in plant (%) | Total N uptake (mg/plant) | The uptake of N derived from HV$_{2011}$ (%N$_{2011}$) | The rate of N derived from HV$_{2011}$ to the total N (%N$_{2011}$) | NUE derived from HV$_{2011}$ (mg/plant) | NUE derived from HV$_{2011}$ (%N$_{2011}$) |
| N240HV     | 614  | 168 a*            | 1.4 a            | 2377 a            | 57.2            | 2.4 c            | 4.3           | 1099        | 24.8 b        | 44.4 b        |
| N80HV      | 651  | 149 b             | 1.2 b            | 1760 b            | 58.9            | 3.4 b            | 4.5           | 983         | 34.4 a        | 47.5 ab       |
| N0HV       | 628  | 138 c             | 1.1 c            | 1498 c            | 57.1            | 3.8 a            | 4.3           | 1045        | 37.1 a        | 49.4 a        |
| Mean       | 631  | 152               | 1.2             | 1879             | 57.7            | 3.2             | 4.4           | 1034        | 32.1          | 47.1          |
| Tukey’s test | NS* | *                 | *               | NS               | *               | NS             | *             | NS          | *             | *             |

* Plots of N240HV, N80HV, and N0HV were fertilized with 240, 80, and 0 kg N·ha$^{-1}$ (1200, 400, and 0 mg N/pot), respectively, in both 2011 and 2012, and $^{15}$N-labeled HV and unlabeled HV were applied in 2011 and 2012, respectively (1319 and 935 mg N/pot, respectively).

* HV$_{2011}$ shows the $^{15}$N-labeled HV applied in 2011.

* NUE (nitrogen use efficiency)=the uptake of N derived from HV$_{2011}$ in 2012/amount of N applied in HV$_{2011}$ (1319 mg N/pot from Table 1).

* The values in 2011 show the result of the tomato cultivation in 2011, in the previous study (Sugihara et al., 2013).

* Means followed by different letters and asterisk are significantly different among the treatments at 5%, Tukey’s test.

* NS: not significant.
were no differences in the N uptake derived from HV2011 and NUE, the rate of N uptake derived from HV2011 to total N uptake varied significantly (N240HV: 2.4%, N80HV: 3.4%, and N0HV: 3.8%), and increased slightly with a reduction in chemical N fertilizer.

Soil-remained N derived from HV2011
Soil-remained N derived from HV2011 (Soil-HVN2011) did not differ among the treatments both before and after the tomato cultivation (Table 3). Comparing before with after cultivation in 2012, Soil-HVN2011 was significantly decreased after the tomato cultivation. Soil-HVN2011 after cultivation in 2012 was also lower than that after 2011 cultivation.

Dynamics of HV2011-derived N
After cultivation in 2011, 44.4%–49.4% of HV2011-derived N was absorbed by tomatoes, 46.6%–56.8% remained in the soil, and 2.1% was leached, or denitrified (Fig. 2; Tables 2 and 3). After cultivation in 2012, 4.3%–4.5% of HV2011-derived N was absorbed by tomatoes, 32.1%–43.2% remained in the soil, and 11% was leached, or denitrified.

Nitrogen distribution
Comparing the distribution ratio of N derived from HV2011 with those derived from soil, fertilizer, and HV2012 in fruits of tomatoes, the former was 45.6%, higher than 42.4% in the latter (average of three treatments with HV) (Table 4). In particular, the distribution ratio of N derived from HV2011 in lower fruit clusters (1st: 12.8%, 2nd: 12.4%), that derived from HV2011 tended to be higher than those derived from soil, fertilizer, and HV2012.

Discussions

Tomato yield
Tomato yield in 2012 was about 40% lower than that in 2011 (Sugihara et al., 2013) (Table 2). This reduction might be due to the replant failure. In addition, the climate difference between two years might affect that yield. In fact, another experiment conducted at the same time using virgin soil in 2012 showed about 25% reduction of fruit yield compared with that in 2011 (not shown). Even though the yield reduction was caused by a climate difference, a 15% reduction was thought to be caused by continuous cropping soil. This experiment was conducted in Wagner pots, suggesting that the content of soil was so small that soil nutrients were exhausted by tomato cultivation even if HV and chemical fertilizer were applied in 2012.

Effect of HV2011 on tomato growth in 2012
The NUE derived from HV2011 in 2012 cultivation (recovery rate) was about 4.4% (Table 2). This value was remarkably lower than that in 2011, closed to 50% (Sugihara et al., 2013). Other studies have reported that the recovery rate of N derived from HV applied in the previous year represented from 2.3% to 3.8% in maize (Acosta et al., 2011), 3.5% in corn (Seo et al., 2006), and 2.5% in irrigated oats (Avena sativa L.) (Cueto-Wong et al., 2001). These results corresponded to the low value (4.4%) in the present study, though these experiments used field crops as material. The low NUE indicates that HV applied in the first year has little ef-
fert on tomato growth in the second year. Thus, the amount of chemical fertilizer cannot be reduced in the second year if HV is applied only in the first year. However, a small amount of N derived from HV contributed to the tomato growth, and remained in the soil after cultivation in 2012. Thus if such a cropping system, HV and subsequently tomato production continue for several years, HV residues may gradually accumulate in the soil. As a result, N derived from HV applied several years ago may be used by tomatoes. Kuo and Jellum (2000) showed the long-term effect of winter cover crops (HV, rye, and ryegrass) on corn growth for 9 years. Therefore, it was suggested that HV had not only the short-term effect, but also the long-term effect on cash crops in N supply.

The distribution ratios of N derived from HV2011 to 1st and 2nd FC clusters were relatively higher than those derived from soil, fertilizer, and HV2012, although there was no significant difference (Table 4). Our previous study showed that the distribution ratios of HV-derived N to low fruit clusters were significantly higher than those of N derived from soil and fertilizer (Sugihara et al., 2013). In the 2012 examination, the distribution ratios of N derived from soil and fertilizer to 1st and 2nd FC should be lower than 12.8% and 12.4% shown in Table 4. Therefore, the distribution ratios of N derived from HV2011 to 1st and 2nd FC may be significantly higher than those derived from soil and fertilizer. Since 1st and 2nd FC developed in a relatively early growth period, it was suggested that the uptake of N derived from HV applied in the previous year occurred mainly in the early period of tomato growth, as well as HV applied in the present year.

These results are suggested to be due to the remaining form of HV-derived N, and the soil storage condition before the experiment. Some researchers reported that N derived from cover crop residues was more likely to be recovered in soil organic N than N derived from inorganic fertilizer, because the cover crop residues contain both C and N compared with inorganic fertilizer N, which does not contain C (Harris et al., 1994; Seo et al., 2006; Varco et al., 1993). Therefore, it was suggested that most of the N derived from HV2011 before the experiment might remain in soil in the form of organic N. It is known that the organic matter decomposition rate depends on soil moisture and temperature (Honeycutt and Potaro, 1990; Ruffo and Bollero, 2003), but pots stored for the experiment 2012 did not receive water during the storage period from autumn 2011 to spring 2012. Furthermore, the air temperature during the storage period was also lower than the optimal temperature for decomposition. As a result, it was suggested that HV2011 residues remained without decomposition during the storage period. At the start of this experiment, the decomposition of HV2011 residues immediately started because the soil was irrigated, and

| Organ | Position | Distribution ratio of N derived from HV2011 (%) | Distribution ratio of N derived from soil, fertilizer, and HV2012 (%) | t-test* |
|-------|----------|-----------------------------------------------|---------------------------------------------------------------|--------|
| Leaf  | Under 2nd FC | 17.5 ± a | 18.4 ± a | NS |
|       | 2nd–4th FC  | 4.5 ± b | 4.3 ± b | NS  |
|       | 4th–6th FC  | 1.0 ± c | 1.1 ± c | NS  |
|       | Upper 6th FC| 0.3 ± c | 0.3 ± c | NS  |
| Leaf  | Leaf total  | 23.3 | 24.2 | NS  |
|       | Stem       | 2.7 ± a | 8.5 ± a | ** |
|       | Under 2nd FC| 7.4 ± a | 8.5 ± a | ** |
|       | 2nd–4th FC  | 1.7 ± b | 1.8 ± b | NS  |
|       | 4th–6th FC  | 0.7 ± c | 0.7 ± c | NS  |
|       | Upper 6th FC| 0.3 ± c | 0.4 ± c | NS  |
| Stem  | Stem total  | 10.1 | 11.3 | *  |
| Root  | 21.0 | 22.1 | NS  |
| Fruit | 1st FC     | 15.6 ± a | 12.8 ± a | NS  |
|       | 2nd FC     | 13.9 ± a | 12.4 ± a | NS  |
|       | 3rd FC     | 7.3 ± b | 7.8 ± b | NS  |
|       | 4th FC     | 6.6 ± b | 7.1 ± b | NS  |
|       | 5th FC     | 1.0 ± c | 1.1 ± c | NS  |
|       | 6th FC     | 1.1 ± c | 1.3 ± c | NS  |
| Fruit | Fruit total | 45.6 | 42.4 | *  |

* FC: fruit cluster, 2nd–4th FC: between 2nd and 4th FC, 4th–6th FC: between 4th and 6th FC. 
** The value means the average of three treatments (N240HV, N80HV, and N0HV). 
* Means followed by different letters are significantly different among positions in each organ at 5%, Tukey’s test. 
** * and ** show that the average values are significantly different between distribution ratio of N derived from HV2011, and that derived from soil, fertilizer, and HV2012 at 5% and 1%, respectively by Student’s t-test. 
NS: not significant.
air temperature gradually rose. Therefore, it was suggested that the uptake of N derived from HV applied in the previous year occurred mainly in the early period of tomato growth, and after HV was applied in the following year in the present study.

**Conclusion**

In the present study, the N derived from HV applied in the previous year contributed slightly to the tomato growth, especially in the early growth stages. Although the contribution rate of N derived from HV applied in the previous year was much lower than that from HV applied in the current year, it was suggested that HV could be used as not only a short-term N source but also as a long-term N source, similar to other organic materials. The results of this study may contribute to developing the HV-tomato rotation cropping system. Further examination will be necessary in greenhouses and plastic houses for establishing cropping system using N fixed in HV.

**Acknowledgements**

The authors wish to deeply thank Mr. Hideki Nakano and Ms. Satoko Takamushi, technicians of the Field Science Center for Northern Biosphere, Hokkaido University, for their valuable technical support with tomato cultivation. We also wish to thank Ms. Aiko Agui, technician of the Graduate School of Environmental Earth Science, Hokkaido University, for her pivotal technical support with N analysis.

**Literature Cited**

Acosta, J. A. A., T. J. C. Amado, A. Neergaard, M. Vinther, L. S. Silva and R. S. Nicoloso. 2011. Effect of 15N-labeled hairy vetch and nitrogen fertilization on maize nutrition and yield under no-tillage. Rev. Bras. Ciênc. Solo 35: 1337–1345.

Araki, H. and M. Ito. 1998. Soil properties and vegetable production with organic mulch and no-tillage system. Japan. J. Farm Work Res. 34: 29–37.

Araki, H., S. Hane, Y. Hoshino and T. Hirata. 2009. Cover crop use in tomato production in plastic high tunnel. Hort. Environ. Biotechnol. 50: 324–328.

Asagi, N. and H. Ueno. 2009. Nitrogen dynamics in paddy soil applied with various 15N-labelled green manures. Plant Soil 322: 251–262.

Blevins, R. L. and W. W. Frye. 1993. Conservation tillage: An ecological approach to soil management. Advances in Agronomy 51: 33–78.

Cavigelli, M. A. and S. J. Thien. 2003. Phosphorus bioavailability following incorporation of green manure crops. Soil Sci. Soc. Am. J. 67: 1186–1194.

Creamer, N. G., M. A. Bennett, B. R. Stinner and J. Cardina. 1996. A comparison of four processing tomato production systems differing in cover crop and chemical inputs. J. Amer. Soc. Hort. Sci. 121: 559–568.

Cueto-Wong, J. A., S. J. Guldman, W. C. Lindemann and M. D. Remmenga. 2001. Nitrogen recovery from 15N-labeled green manure incorporation. J. Sustain. Agr. 17: 43–55.

Harris, G. H., O. B. Hesterman, E. A. Paul, S. E. Peter and R. R. Janke. 1994. Fate of legume and fertilizer nitrogen-15 in a long-term cropping systems experiment. Agron. J. 86: 910–915.

Honeycutt, C. W. and L. J. Potaro. 1990. Field evaluation of heat units for predicting crop residue carbon and nitrogen mineralization. Plant Soil 125: 213–220.

Hoyt, G. D. and W. L. Hargrove. 1986. Legume cover crops for improving crop and soil management in the southern United States. HortScience 21: 397–402.

Kumar, V., A. A. Abdul-Baki, J. D. Anderson and A. K. Mattoo. 2005. Cover crop residues enhance growth, improve yield, and delay leaf senescence in greenhouse-grown tomatoes. HortScience 40: 1307–1311.

Kuo, S. and E. J. Jellum. 2000. Long-term winter cover cropping effects on corn (Zea mays L.) production and soil nitrogen availability. Biol. Fertil. Soils 31: 470–477.

Langdale, G. W., R. L. Blevins, D. L. Karlen, D. K. McCool, M. A. Nearing, E. L. Skidmore, A. W. Thomas, D. D. Tyler and J. R. Williams. 1991. Cover crop effects on soil erosion by wind and water. p. 15–22. In: W. L. Hargrove (ed.). Cover crops for clean water. Soil and Water Conservation Society, Iowa.

Ruffo, M. L. and G. A. Bollero. 2003. Modeling rye and hairy vetch residue decomposion as a function of degree-days and decomposition-days. Agron. J. 95: 900–907.

Seo, J. H., J. J. Meisinger and H. J. Lee. 2006. Recovery of nitrogen-15-labeled hairy vetch and fertilizer applied to corn. Agron. J. 98: 245–254.

Sugihara, Y., H. Ueno, T. Hirata and H. Araki. 2013. Uptake and distribution of nitrogen derived from hairy vetch used as a cover crop by tomato plant. J. Japan. Soc. Hort. Sci. 82: 30–39.

Teasdale, J. R. 1993. Reduced-herbicide weed management systems for no-tillage corn (Zea mays) in a hairy vetch (Vicia villosa) cover crop. Weed Technol. 9: 113–118.

Teasdale, J. R. and A. A. Abdul-Baki. 1995. Soil temperature and tomato growth associated with black polyethylene and hairy vetch mulches. J. Amer. Soc. Hort. Sci. 120: 848–853.

Thönissen, C., D. J. Midmore, J. K. Ladha, R. J. Holmer and U. Schmidhalter. 2000. Tomato crop response to short-duration legume green manures in tropical vegetable system. Agron. J. 92: 245–253.

Varco, J. J., W. W. Frye, M. S. Smith and C. T. MacKown. 1993. Tillage effects on legume decomposition and transformation of legume and fertilizer nitrogen-15. Soil Sci. Soc. Am. J. 57: 750–756.