Chapter 5

Tomato Production with Cover Crops in Greenhouse

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Additional information is available at the end of the chapter

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Abstract

One of the ways to reduce chemical fertilizer application is the use of cover crops, which improve soil properties and supply nutrition to subsequent crops. Hairy vetch (*Vicia villosa* R.; HV) is one of the processing legume cover crops. A similar yield of fresh marketable tomato (*Solanum lycopersicum* L.) was obtained in the soil with HV mulch and incorporation even if the reduction of chemical N fertilizer input compared with the conventional production with 240 kg-N/ha fertilizer in the greenhouse from 2006 to 2012. Using 15N-labeling method, HV residue incorporated into soil was decomposed rapidly for about 1 month and N released from HV residue was absorbed into the tomato plant. Nitrogen was absorbed by tomato through out production period. The rate of N uptake derived from HV to total N uptake in tomato plants (%N_{dfhv}) in the small amount N fertilizer was higher than that with high amount of N fertilizer application. It ranged from 24.8% in 240 kg-N/ha to 37.1% in no N fertilizer. The nitrogen use efficiency (NUE) from HV-derived N by tomato plant reached about 50% during the tomato production with HV incorporation. Other 50% of HV-derived N remained in the soil and 4% of were absorbed by tomato in the next year's production. HV has the possibility of alternative material for basal N fertilizer to ensure the tomato growth of early period after transplanting, and continuous supply of N is necessary to late stage of tomato. The combined system of incorporation of HV cultivated at the seeding density of 20–50 kg/ha before tomato planting and the slow released N fertilizer was established for the reduction N fertilizer application and obtaining conventional tomato yield in plastic house.

Keywords: cover cropping, hairy vetch, nitrogen, nitrogen dynamics, tomato

1 Introduction

1.1 Management of fertilizer application in tomato production in plastic house

More than 70% of fruit vegetables including tomato were repeatedly produced with the application of much amount of chemical fertilizer in plastic house in Japan, and salt accumulation and injury by continuous cropping became serious problems. Excessive N input causes extra N accumulation in the soil [1], as a result of environmental pollution, such as nitrate leaching and greenhouse gas emission occur [2]. For the establishment of sustainable greenhouse production, reducing fertilizer inputs and proper applications are required.

Because tomatoes are produced with N application by basal and side-dressing fertilizer in practice, the dynamics of N derived from basal, side-dressing fertilizer, and soil in the plant are complicated, and real-time nutritional diagnosis was developed [3, 4].

Side dressings of fertilizer combined with diagnosis of nutrient conditions are popularly carried out in production areas [4, 5]. Leaf petioles below the first fruit cluster or upper fruit cluster with 2–4 cm size tomatoes are used as material for the nitrate analysis. Nitrate concentration of ca 3000–4000 ppm was reported to be an appropriate concentration for vegetative growth in tomato.

Controlled release fertilizer, the so-called slow-release fertilizer, is applied at the beginning of tomato production to reduce application work. These fertilizer management methods contribute to proper nutrient application in tomato production. However, for sustainable tomato production in greenhouses or plastic houses, soil properties have to be improved and be healthy in addition to proper N fertilization.

1.2 Advantage of cover cropping

Planting a cover crop is one of the biological tools used for sustainable crop production, which has the effects of N supply [6], increasing organic soil carbon [7], improving soil physical properties [8], and so on. Among the various kinds of cover crops, hairy vetch (*Vicia villosa* R.; HV), legume crop, is one of the important species. HV residues can supply plenty of N due to its efficiency in biological nitrogen fixation [9, 10]. HV also has other advantages, such as adaptability to low temperatures, resistance to pests, delaying senescence, covering ground surface effectively, and fitness for vegetable production, particularly in rotation with tomatoes [11]. Araki et al. [7] also reported that utilizing HV could reduce chemical N fertilizer inputs to half of the recommended amount without yield reduction in tomato production. Such results showed that HV had potential as an alternative fertilizer to chemical N fertilizers.

The N release pattern from inorganic or organic fertilizer has to be synchronized with crop demands for proper application [12]. Yaffa et al. [13] have shown the synchronization of tomato N uptake and N release from cover crops; the tomato N uptake increased after the increase of soil inorganic N, followed by a decline. On the other hand, Kumar et al. [11] reported that because N release from white clover residues was faster under rotary hoeing treatment, it was not synchronized with the N demand of wheat during its early growth period and resulted in minimum N-benefits. We have to investigate the N supply pattern when HV was introduced in tomato cropping in plastic house.

Non-legume cover crops are higher in carbon than legume cover crops. Because of their high carbon content, grasses break down more slowly than legumes, resulting in longer-lasting residue. As grasses mature, the carbon-to-nitrogen ratio (C:N) increases. This has two tangible results: The higher carbon residue is harder for soil microbes to break down, so the

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process takes longer, and the nutrients contained in the cover crop residue usually are less available to the next crop.

2 Tomato production with cover crops, 2006–2012

2.1 Field preparation and chemical fertilizer application

Tomatoes were grown in the rows with or without cover crop residue mulch shown in **Table 1**, in high plastic tunnels, adding nitrogen fertilizer 120 kg and 240 kg/ha, 2006 and 2007.

Date	Operation
March 22	Cover plastic film
April 4	Surface tillage in each row
April 5	Sowing of cover crop
May 26	Mowing of cover crop
	Application of fertilizers
	Making an organic mulch
May 29	Planting of tomato seedings
	Measurement of nitrate in leaf petiole and growth index
July 7–	Tomato harvest every 2–3 days
October 15	
November 16	Measurement of Soil N and C

Source: Araki et al., Hort. Environ.Biotechnol. 50:324-328. 2009.

Table 1. Field operation in the tomato production with cover crop, 2007.

Hairy vetch (*Vicia villosa* R.) and wild oat (*Avena sterigosa* L.) were used for cover crop. They were drill planted at 10–15 cm distance, each alone or together on April 5. Seeding density was 50 kg/ha in hairy vetch, 100 kg/ha in wild oat, and 35 and 50 kg/ha in hairy vetch and wild oat, respectively. Cover crops were grown until May 26 and mowed by cutter 2 cm above the ground surface for making residue mulch of cover crops. The plots with cover crops were left untilled to maintain the residue mulch, and bare plot without cover crops were slightly tilled by hand (**Table 2**, **Figure 1**).

Year Examined	Mark	Cover crop		Fertilizer		
		Spices	Treatment	N^z (kg/ha)	P_2O_5 (kg/ha)	K_2O (kg/ha)
2006–2007	N240	Nothing	Bare	240	200	200
	N120	Nothing	Bare	120	200	200

Year Examined	Mark	Cover crop		Fertilizer		
		Spices	Treatment	N^z (kg/ha)	P_2O_5 (kg/ha)	K_2O (kg/ha)
	HV	HV	Mulch	120	200	200
	Oats	Oats	Mulch	120	200	200
	Mix	HV + oats	Mulch	120	200	200
2008	N240	Nothing	Bare	240	200	200
	N80	Nothing	Bare	80	200	200
	HV	HV	Mulch	80	200	200
	Oats	Oats	Mulch	80	200	200
	Mix	HV + oats	Mulch	80	200	200
2009–2012	N240	Nothing	Bare	240	200	200
	HV	HV	Incorporation	80	200	200
	HV	HV	Mulch	80	200	200
	Oats	Oats	Mulch	80	200	200
	Mix	HV + oats	Mulch	80	200	200

^{z}In both N rates, 20 and 80% of total N fertilizer were applied by fast-release (ammonium sulfate) and slow-release fertilizer (LPS100, N40%), respectively.
Source: Araki et al., Hort. Environ. Biotechnol. 50:324-328. 2009.

Table 2. Hairy vetch treatment and fertilizer application in tomato plots from 2006 to 2012.

Figure 1. Cover crops grown in plastic high tunnel (1), hairy vetch reside mulch plot (2) and bare plot (3).Source: Araki et al., Hort. Environ. Biotechnol. 50:324–328. 2009.

Chemical fertilizers for tomato were applied on the ground surface on May 27, 2006. Two rates of nitrogen fertilizer of 120 and 240 kg/ha were applied in the bare rows, and 120 kg N/ha fertilizer was done in rows with cover crops. In both N rates, 20 and 80% of total N fertilizer were applied by fast-release (ammonium sulfate) and slow-effect fertilizer (LP40, Chisso ASAHI Co. Ltd.), respectively (**Table 2**). In every plot, 200 kg of P_2O_5 and K_2O was added per ha.

Each plot was 0.8 m wide and 3 m long, 0.6 m between tomato lines and 0.5 m between plants. Planting density was 22,220 plants/ha. Treatments were arranged in a randomized block design with three replications.

Tomato production with cover crops was continued till 2012. N fertilizer application in cover crop plots reduced to 80 kg/ha from 2008, and the plot of HV incorporation was set up from 2009.

2.2 Biomass production of cover crops

Wild oat grew to heading stage; however, seeds were not developed at the mowing time. Flowering occurred in some HV plants. At the mowing, late in May, contents of N and C were 4.3 and 41.3% in HV (C/N: 10.1), and 1.4 and 37.1% in oats (C/N: 32.3) in average from 2007 to 2012 (**Table 3**).

Cover	Concentration		N,C	FW			DW			N Contents (kg/ha)
Crop	N (%)	C (%)	C/N ratio	HV (kg/ha)	Oats (kg/ha)	Total (kg/ha)	HV (kg/ha)	Oats (kg/ha)	Total (kg/ha)	
HV	4.3	41.3	10.1	33,000	–	33,000	4,709		4,709	203
Oats	1.4	37.1	32.3	–	28,270	28,270	–	5,301	5,301	87
Mix				11,570	26,270	37,840	1,595	4,950	6,545	148

Data was the average of values obtained from 2007 to 2012.

Table 3. Biomass production of cover crops, hairy vetch and oats, cultivated in the plastic house for 2 months, April and May. 2007–2012.

Aboveground biomass (dry weight) was 4709 kg/ha in HV and 5301 kg/ha in wild oat late in May. However, in mix-culture, it was 1595 kg/10a in HV and 4950 kg/ha in wild oat.

Sainju et al. [14] reported that bi-culture of legume and non-legume cover crops had greater biomass yield, and also N and C contents in cover crops than monoculture of each species in the southeast area of USA. On the other hand, aboveground and underground biomass yield, and N and C contents of cover crops were varied by year and experimental location.

Experimental location of this examination, Sapporo, Japan, was snow cover region. More than 1 m high snow cover is observed in winter. HV is a typical winter annual legume crops originally, but few plants survive after long snow cover [15]. Wild oat also cannot overwinter under snow cover more than 3 month in Sapporo. HV and wild oat were usually sown in early spring in Sapporo. Greater biomass in bi-culture of wild oat and HV was not observed than monoculture of wild oat because of short growing period of cover crops.

2.3 Tomato growth and yield, 2007

2.3.1 Nitrate in petiole sap

There was a difference in nitrate concentration in petiole sap in leaf below first fruit cluster among treatments in July and August. Nitrate in HV plot showed 3650 and 3550 ppm in July and August (**Figure 2**). Those in Bare + N240 kg plot were 3280 and 2966 ppm, respectively. However, nitrate concentrations in other treatments were smaller than those in HV and Bare + N240 kg plots. That in oat plots was smallest. Though nitrate value decreased from July to August in bare plot (N120 kg), it increased in oat and mix (HV + Oat) plots. Such observation accorded with the result that N content became high in the leaves of tomatoes produced with HV mulch [16].

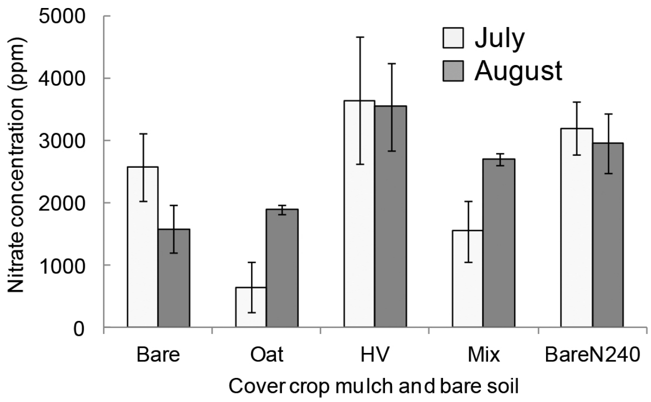

Figure 2. Effect of cover crop residue mulch on nitrate concentration of petiole sap on July 9 and August 10, 2007. 240 kg N fertilizer per ha was added into BareN240 plot and 120 kg N fertilizer per ha was done into other plots. Vertical bars represents SE (n = 3).Source: Araki et al., Hort. Environ. Biotechnol. 50:324–328. 2009.

2.3.2 Growth and yield of tomato

Similar total marketable yield was shown in HV and Bare + N240 kg plots, 78.2 t/ha in the former and 79.5 t/ha in the latter (**Figure 3**). Yield in first and second fruit cluster in Bare + N240 kg plot was larger than those in HV plot. Yields in Bare + N120 kg and mix plots were 68.8 t and 69.6 t/ha, smaller than those in HV and Bare + N240 kg plots. Oat plot showed smallest yield, 61.5 t/ha.

To consider fruit yield, nitrogen absorption/application rate, and nitrate nitrogen concentration, the proper range of petiole sap nitrate concentration was 4000–7000 ppm [4]. This has been recognized as recommendable value of nitrate concentration for current yield in Hokkaido prefecture. In this examination, nitrate concentrations in petiole sap in HV and Bare + N240 kg plots were close to the recommendable value in July and August. These plots have possibility to obtain the current yield. Those in other plots were obviously lower than recommended value, and it is necessary to apply the N fertilizer for the current yield.

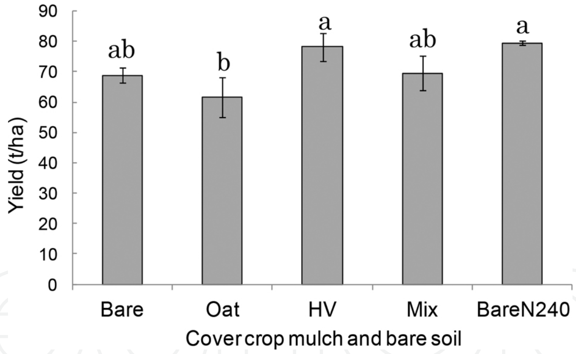

Figure 3. Effect of cover crop residue mulch on total fresh marketable yield of tomato 2007. 24 kg N fertilizer per 10a was added into BareN24 plot and 12 kg N fertilizer per 10a was done into other plots. Vertical bars represent SE (n = 3). Means followed by different letters are significantly different at 5%, Tukey's test.Source: Araki et al., Hort. Environ. Biotechnol. 50:324–328. 2009.

In bare plots, especially adding with N120 kg, nitrate concentration in petiole tended to decrease from July to August; however, it increased in oat and mix plots in spite of same rate of N fertilizer. It is caused by decomposing the organic matter of cover crop residue applied in 2006 and 2007.

Nitrate concentration in petiole sap was concerned with growth index (GI), indicator of vegetative growth. GI values in Bare + N240 kg and HV plots were higher than other cover crop plots. HV, typical legume crops, decomposes faster than non-legume crops because of low C/N ratio [17], and released nitrogen is absorbed into tomato plant. However, C/N ratio of wild oat is high, as much as 24 in our previous observation. Nitrogen absorbance into tomato plants was restricted due to immobilization in soil.

Same trend in marketable tomato yield was observed as GI, with larger yield in Bare + N240 kg and HV plots, medium yield in Bare + N120 kg and mix plots and smallest in oat plots. The examined location is a cool summer region of which air temperature usually decreases from September. It is necessary to obtain good vegetative growth until August for getting much yield.

Even if N fertilizer decreases to half of conventional (240 kg/ha), current tomato yield was obtained in the HV plots. Such tomatoes are recognized as organically grown agro-product in combined with the reduction of fungicide and pesticide application.

2.4 Long-term evaluation of tomato yield, 2007–2012

Such tomato production system continued till 2012 (**Table 4**). The vegetative growth (GI) and marketable yield showed same trend as 2007. That is, highest GI and yield were shown in Bare-N240 plot. However, there was no significant difference between Bare-N240 and HV (N80 kg)-incorporation. GI and marketable yield of HV mulch plot were a little smaller than those of Bare-N240 and HV (N80 kg)-incorporation. From the long-term examination, 2008–2010, it was clarified HV supports the vegetative growth and tomato yield even if N fertilizer reduces to half or one third of conventional application in greenhouse.

Mark (cover crops)	Treatment of cover crops	N fertilizer[y] (kg/ha)	Growth index[x]		Marketable yield (t/10a)	
N240	Bare	240	40514	a[w]	4.7	a
HV	Incorporation	80	38424	a	4.3	a
HV	Mulch	80	33200	b	4.1	a
Oats	Mulch	80	25365	c	2.6	b
Mix	Mulch	80	29.336	bc	3.0	b
Tukey's test[w]			*		*	

[z]Data was average of the values obtained from 2007 to 2012.
[y]In both N rates, 20 and 80% of total N fertilizer were applied by fast-release (ammonium sulfate) and slow-release fertilizer (LPS100), respectively.
[x]Growth index (GI) was measured 6 weeks after transplanting, just before the first harvest.
[w]Means followed by different letters and asterisk are significantly different among the treatments at 5%, Tukey's test. NS: not significant.

Table 4. Effects of cover crops and N fertilizer on the growth and the yield of tomato: 2007–2012[z].

2.5 Soil N and C content after tomato production

Increase of inorganic N increased near soil surface, 0–5 cm depth, in the rows with cover crops in the case of N 120 kg/ha application, 2007. Considering the high nitrate in petiole, high GI and large yield in plots with HV, it is thought that released N from cover crops was absorbed into tomato plants in near soil surface. There was no significant difference in soil total N among the plots though the examination period (**Table 5**).

Mark (cover crops)	Treatment of cover crops	0.5 cm				15 cm			
		N (%)		C (%)		N (%)		C (%)	
		2007	2012	2007	2012	2007	2012	2007	2012
N240	Bare	0.28	0.22	3.89	3.57	0.24	0.22	3.54	3.50
HV	Incorporation	0.24	0.26	3.45	3.51	0.23	0.22	3.35	3.50
HV	Mulch	0.30	0.24	4.24	3.87	0.24	0.23	3.70	3.32
Oats	Mulch	0.27	0.23	4.08	3.69	0.25	0.23	3.57	3.55
Mix	Mulch	0.30	0.27	4.61	4.07	0.26	0.25	3.77	3.78

Data in 2007 and 2012 were presented.

Table 5. Content of total nitrogen and total carbon in the soil of the plot cultivated cover crops for 7 years (2006–2012), at the depth 5 cm and 15 cm.

As to soil carbon, the change of soil C content was observed in of 0–5 cm depth soil because of leaving cover crop residue on the soil surface. There was tendency to increase in mix plot (oats and HV); however, significant difference was recognized only 2 years, 2007 and 2008.

Winter cover crops have the potential to increase soil organic C in agricultural soils [18]. Komatsuzaki and Mu [19] evaluated the effects of tillage in continuous field rice cropping with rye and hairy vetch cover crops in Kanto region, non-snow cover region in Japan. Soil organic carbon in the top soil, 0–2.5 cm depth, increased compared with winter fallow 2 years later adopting cover cropping; however, other soil layer did not show any change in their observation.

Organic matter level in the soils under mixed cover crops improved as much as 8.8% after 3 years of cover crop use [20]. Interestingly, soil under the legume-only cover actually dropped slightly in organic matter content after 3 years, probably because the lower C/N ratio of the incorporated organic matter caused more rapid microbial breakdown. Soil C varies from year-to-year as a result of weather-affected changes in crop residue inputs or decomposition of residues and organic matter [21].

As to one of the reasons of little change of soil C in our examination, ash soil is distributed around plot area and soil C content is originally high, more than 3%. If the examination was performed in the soil with low content of soil C, soil C will increase using of cover crop, especially no legume cover crops. Content of soil C affects the biological properties of soil. Some methods such as active carbon and SIR (substrate-induced respiratory) are applied for the estimation of diversity of microorganisms.

3 N dynamics in tomato production with HV

3.1 Stable isotope technique

These results mentioned previous section showed that HV could be alternative fertilizer for crop production instead of chemical N fertilizer and become a useful tool to solve the high input problem in N management. It is important to clarify the tomato uptake of N mineralized from HV residue for the establishment of effective N management in the cropping system with cover crops.

The method using ^{15}N-labelled plant materials has been effective for direct estimation of N uptake from the cover crops. Earlier studies have found that the N uptake by the subsequent crop was 6–25% of N applied by ^{15}N-labelled cover crops, HV, ryegrass, etc [10, 22–25]. The efficiency differed depending on subsequent crop species, cover crop species, or cultivation circumstances.

In tomato production with cover crops, Thönnissen et al. [26] reported that when legumes were incorporated or mulched into the soil, tomato absorbed 8.9 or 9.6% of soybean-derived N and 10.0 or 15.0% of indigofera-derived N, respectively. In other report, the higher recovery rate of cover crop-derived N was also reported; 56% of HV-derived N was recovered by rice [27]. ^{15}N-labeling method was used in the evaluation of N recovery from cover crops in these reports.

The application effect of legume cover crop, hairy vetch (*Vicia villosa* R.; HV), on N dynamics in fresh market tomato (*Solanum lycopersicum* L.), "House Momotaro," was investigated using

^{15}N-labelling method [28]. Tomato seedlings were transplanted in the 1/2000a Wagner pot at 0, 80, 240 kg ha^{-1} of N application (N0HV, N80HV and N240HV) on June 9. Before transplanting, the labeled HV (0.86 atom% excess) and chemical fertilizer were incorporated into soil.

3.2 Absorption and distribution N derived from HV

HV-derived N uptake was recognized mainly in first 4 WAT. Especially, in N240HV, the uptake of HV-derived N ceased at 4 WAT. The uptake amounts of HV-derived N at 10 WAT were 587, 657, and 729 mg plant^{-1} in N240HV, N80HV, and N0HV, respectively, and there were significant differences among three treatments (**Figure 4**). The ratio of N uptake derived from HV to total N uptake in tomato plants (%N_{dfhv}) was the highest at 2 WAT, and %N_{dfhv} in N80HV (52.1%) and N0HV (51.5%) were significantly higher than in N240HV (43.6%) (**Figure 5**). After 2 WAT, %N_{dfhv} was decreased gradually in all N rates as tomatoes grew, and it was decreased to 24.8, 34.4, and 37.1% in N240HV, N80HV, and N0HV, respectively, until 12 WAT (**Figure 6**). The nitrogen use efficiency (NUE) by tomato plant from HV-derived N was the highest at 10 WAT, and N0HV (55.3%) was significantly higher than N240HV (44.5%) and N80HV (49.8%) (**Table 5**).

The partition rate of HV-derived N into fruits was 63.9 and 39.7% of HV-derived N was partitioned into low fruit clusters, first and second. The partition rate of N derived from soil and fertilizer into fruits was 57.9%, significantly lower than that of HV-derived N. From these results, it was clarified that (1) HV-derived N was used effectively in small rate of chemical N fertilizer and (2) the N supply effect from HV was expressed in early period of tomato growth (**Table 6**).

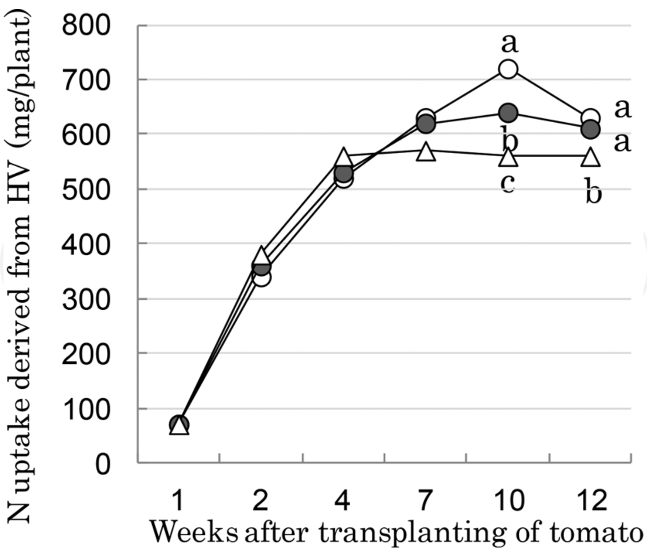

Figure 4. Effect of N fertilizer and HV treatment on the increase of the amount of tomato plant N uptake derived from HV. The plots of N0HV (○), N80HV (●), and N240HV (Δ) were fertilized 0, 80, and 240 kg N ha^{-1}, respectively, and applied HV (1319 mgN pot^{-1}). Means followed by different letters are significantly different at 5%, Tukey's test.Source: Sugihara et al., J. Japan. Soc. Hort. Sci. 82: 30–38. 2013. Available online at www.jstage.jst.go.jp/browse/jjshs1

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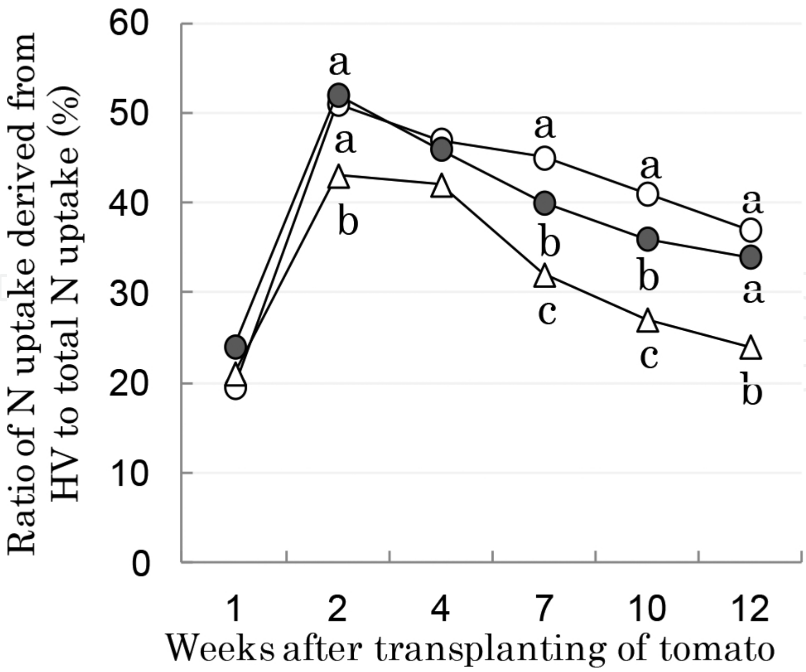

Figure 5. Effect of N fertilizer and HV treatment on the change of the ratio of plant N uptake derived from HV to total N uptake. The plots of N0HV (○), N80HV (●), and N240HV (Δ) were fertilized 0, 80 and 240 kg N ha^{-1}, respectively, and applied HV (1319 mgN pot^{-1}). Means followed by different letters are significantly different at 5%, Tukey's test.Source: Sugihara et al., J. Japan. Soc. Hort. Sci. 82: 30–38. 2013. Available online at www.jstage.jst.go.jp/browse/jjshs1

Treatment[z]	Nitrogen use efficiency (%)							
	Weeks after transplant (WAT)							
	1	2	4	7	10		12	
N240HV	5.1	29.4	43.4	45.2	44.5	c[y]	44.4	b
N80HV	4.8	27.8	41.2	48.7	49.8	b	47.5	ab
N0HV	4.4	25.9	40.3	49.9	55.6	a	49.4	a
Tukey's test[y]	ns[y]	ns	ns	ns	*		*	

[z]The plots of N240HV, N80HV and N0HV were fertilized 240, 80 and 0 kg N ha^{-1}, respectively, and applied HV (1,319mgN pot^{-1}).
[y]Means followed by different letters and asterisk are significantly different among the treatments at 5%, Tukey's test.
NS: not significant.
Source: Sugihara et al., J. Japan. Soc. Hort. Sci. 82: 30-38. 2013. Available online at www.jstage.jst.go.jp/browse/jjshs1

Table 6. Effect of N fertilizer and HV treatment on nitrogen use efficiency (NUE) derived from HV.

3.3 Combination of N fertilizer, HV, fast-release N and slow-release N

In order to improve the use efficiency of both hairy vetch (*Vicia villosa* R.; HV) and chemical N fertilizer, N release and uptake patterns from HV, fast-release N fertilizer (FF), and slow-release N fertilizer (SF) in fresh market tomato (*Solanum lycopersicum* L.) production were investigated using the ^{15}N-labeling method. There was no difference in tomato fruit yield between FF + SF and SF-only. HV-derived N was up taken by the tomatoes mainly until 4 weeks after transplant (WAT). The uptake amount of HV-derived N (N_{dfhv}) was same in the pot with FF + SF and SF-only. The rate of N uptake derived from HV to total N uptake in tomato plants (%N_{dfhv}) was 43% (480/1116 mg) in SF-only, higher than that in FF + SF(35%, 430/1204 mg) at 4 WAT; however, such difference disappeared after 4 WAT (**Table 7**). N uptake by tomato plants was continued 12 WAT. From these results, HV has possibility of alternative material for FF to ensure the tomato growth of early period after transplanting and continuous supply of N is necessary to late stage of tomato.

Treatments[z]	**N uptake (mg/plant)**													
	2 WAT[y]			4 WAT			8 WAT			12 WAT				
	Total[x]	N_{dfhv}	N_{dfhv}	Total	N_{dfsf}	N_{dfhv}	Total	N_{dfsf}	N_{dfhv}	Total		N_{dfsf}		N_{dfhv}
N240HV (FF + SF)	767	508	259	1204	774	430	2010	1518	492	2497	a[w]	1983	a	513
N240HV (SF-only)	745	419	326	1116	636	480	1930	1435	495	2497	a	1959	a	538
N240 (FF + SF)	–	–	–	–	–	–	–	–	–	1748	b	1748	b	–
N240(SF-only)	–	–	–	–	–	–	–	–	–	1786	b	1786	b	–
t-test	NS[v]	*	NS	NS	*	NS	NS	NS	NS	–		–		NS
Tukey's test	–	–	–	–	–	–	–	–	–	*		*		–

[z]Plots of N240HV were fertilized with 240 kg N·ha^{-1}, and HV was applied (1007 mg N/pot^{-1}). Plots of N240 were fertilized with 240 kg N·ha^{-1} without HV. (FF + SF) contained 20% fast-release fertilizer + 80% slow-release fertilizer, and (SF-only) contained 100% slow-release fertilizer.
[y]WAT: weeks after transplant.
[x]Total = N_{dfsf} + N_{dfhv}, N_{dfsf}; N derived from soil and fertilizer, N_{dfhv}; N derived from HV.
[w]Means followed by different letters and asterisk are significantly different among the treatments at 5%, *t*-test and Tukey's test. NS: Not significant.
Source: Sugihara et al., J. Japan. Soc. Hort. Sci. 83: 222–228. 2014. doi: 10.2503/jjshs1.CH-061

Table 7. Effects of N fertilizer and HV treatments on N uptake by tomato plants.

3.4 Absorption of HV-N remained in soil in the following year

After the tomato cultivation in 2011, the soil was stored in a greenhouse without any water and fertilizer. Tomatoes were cultivated again in the Wagner pots in which contained used soil of 2011 and were added same rate of N fertilizer (0, 80, and 240 kg ha^{-1} of N) and unlabeled HV (935 mgN/pot) in 2012. Total N uptake of tomato plant 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 (HV_{2011}, 1319 mgN/pot) was not different among the treatments (57.7 mg/plant on average), so nitrogen use efficiency derived from HV_{2011} in 2012 was 4.4% on average (**Figure 6**). This value was much lower than that in 2011 (47.1% on average), but HV_{2011}-N also remained in the soil yet after the tomato cultivation in 2012 (500 mgN/pot). These results showed that although the N supplying effect of HV was small in the following year, HV could be available for not only short-term N source, but also long-term N

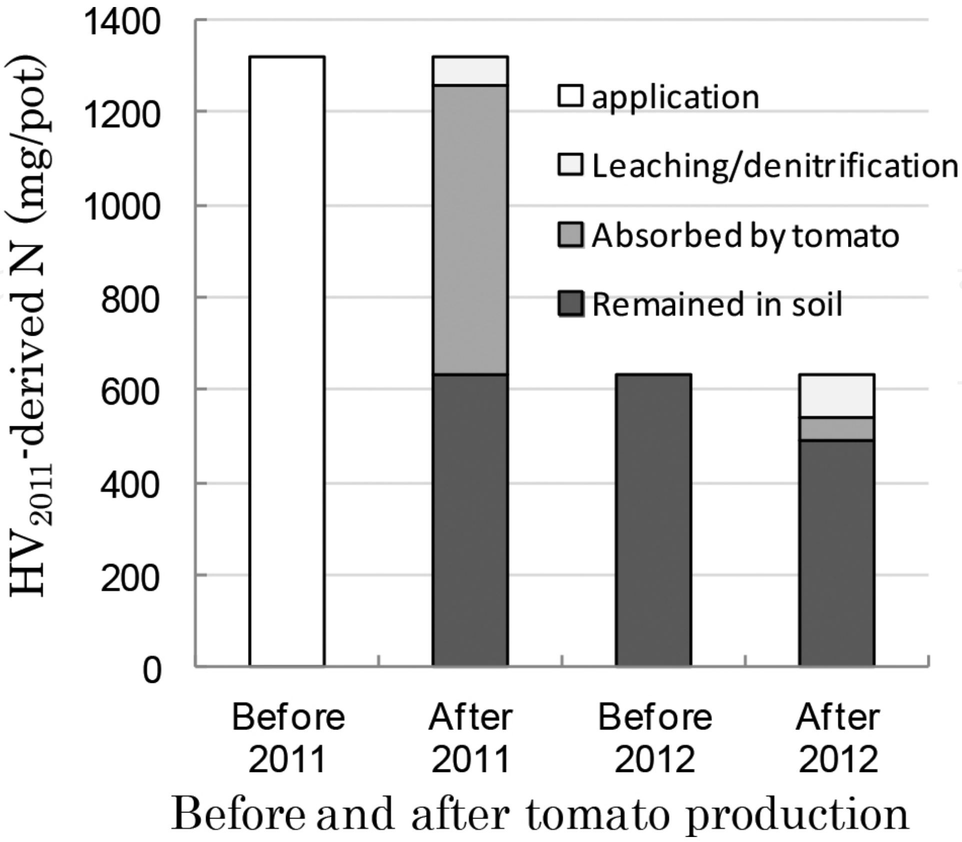

Figure 6. Dynamics of HV_{2011}-N's input and output. The values show an average of three treatments.Source: Sugihara et al., The Horticulture Journal 2016 (preview). doi:10.2503/hortj.MI-073

source, and HV-derived N applied in the previous year was absorbed by tomato plant during relatively early growth period in the following year.

HV-derived N is probably available as alternate of fast-release fertilizer, but in order to cultivate tomato healthy, it is supposed that the application of additional fertilizers for late period growth is needed. Although reducing chemical fertilizer application improves the HV-derived N use efficiency, the excess reducing fertilizer could lead to nitrogen deficiency during late period. Therefore, it is important to balance reducing chemical fertilizers and ensuring normal tomato fruit yield in order to establish the low input sustainable cropping system using HV as a cover crop in tomato cultivation.

From the experiment 2012, the N derived from HV applied in the previous year contributed slightly to the tomato growth, especially in the early growth stage. 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 for not only short-term N source but also long-term N source as same as other organic materials. The result of this study will be able to use as one of the knowledge to establish the HV-tomato rotation cropping system.

4 Proof study of tomato production with HV

The positive responses of tomatoes grown under hairy vetch residues have economic and environmental importance. From the results mentioned above, HV has the possibility of alternative material for basal N fertilizer to ensure the tomato growth of early period after transplanting and continuous supply of N is necessary to late stage of tomato. A proof study to utilize HV in a real house is necessary because the examinations on N dynamics were carried out in Wagner pot.

4.1 Fertilizer design

The application of ammonium sulfate (AS; 100-N kg/ha), HV (two seeding density; 20 kg and 50 kg/ha) and nothing, was for basal fertilizer management (**Table 8**). AS was applied into soil, May 31, 2015, the previous day of tomato planting. HV grew for over 2 months; it was mowed in late May. At the mowing time, flowering was observed in some plants. Aboveground biomass (dry weight) of HV at densities 50 and 20 kg/ha were 7.2 and 5.9 t/ha, respectively. This biomass accounts for the incorporation of organic nitrogen of 252 and 309 kg/ha of equivalency into soil in HV20 and HV50, respectively. The C:N ratio of HV was low, 9.6, suggesting rapid decomposition and mineralization of organic residues after incorporation into soil.

LPS100 (Long player N fertilizer, slow release type, Chisso ASAHI Co. Ltd) was added in all plots for side dressing. Similarly, in every plot, 200 kg/ha of P_2O_5 as fused magnesium phosphate and 200 kg/ha of K_2O as potassium sulfate were added. Transplanting occurred on June 1, 2015.

Fertilizer or hairy vetch	Basal N		Top N LPS100	Yield of marketable	
	HV seeding (kg/ha)	AS-N application (kg/ha)	application (kg/ha)	tomato (t/ha)	
Control	0	0	150	97	c
AS100	0	100	150	114	b
HV20	20	0	150	129	a
HV50	50	0	150	130	a

Yield means followed by different letters are significantly different among the treatments at 5%, Tukey's test.

Table 8. Design of nitrogen application using HV and chemical fertilizer and marketable yield of fresh tomato.

4.2 Soil inorganic nitrogen and tomato yield

AS100 plots exhibited the highest soil inorganic nitrogen (9 mg/100 g) in the second week after transplanting (2 WAT); however, it showed a decreasing trend (**Table 9**). The soil inorganic nitrogen in HV20 and HV50 plots got to increase from 4 WAT until 6 WAT.

Plots	Inorganic nitrogen (mg/100g)		
	WAT		
	2	6	12
Control	2.6	3.1	1.0
AS100	9.0	3.1	1.1
HV2	2.8	5.0	1.6
HV5	5.4	4.0	2.1

Table 9. Change of inorganic nitrogen in the after tomato planting.

Similar and higher marketable yields were found in HV plots, 130 t/ha in HV50 and 129 t/ha in HV20. These yields were higher than those in AS100 and control plots,114 and 97 t/ha, respectively (**Table 8**).

Because of high N accumulation, HV increased soil inorganic nitrogen, tomato yield, and N uptake [29]. The HV residues increased soil inorganic N in the early stages of tomato cultivation. HV released more nitrogen in the first 6 weeks while ammonium sulfate provided more nitrogen in the first 4 weeks after transplanting. The results were in agreement with previous studies [28, 30–32]. The increased level of inorganic N with the HV at 15– 42 days after residue incorporation may indicate that hairy vetch is suitable to be used as N source for the early stages of tomato cultivation.

From this study, 40% of conventional N fertilizers were reduced by incorporating hairy vetch residues in soil, even though good vegetative growth and high marketable yield were obtained.

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