CO₂ Emission and Cost Analysis in Asparagus Fusekomi Forcing Culture with Wood Pellet Boiler

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Domestic fresh asparagus is demanded in Japan from late autumn to winter. Asparagus production in greenhouse in winter needs a large amount of oil or electricity for heating, leading to CO₂ emissions and high costs, and an alternative heating system with low carbon emission is therefore required for winter cultivation of asparagus. Three heating systems were prepared for the asparagus fusekomi forcing culture (FFC) in a plastic greenhouse in mid-winter in Hokkaido, i) conventional system i.e. electrically heated wire system for soil heating, ii) a hot water system for soil heating only, iii) a hot water system for both soil and air heating. Hot water was produced by using wood pellet boiler. Average soil temperature at 14 cm depth in the culture bed remained within 15–20°C in each system. Freeze injury of emerged spears was avoided by the hot water heating, especially in the heating of both soil and air even when the outside temperature fell to −18°C. Hot water heating systems generated larger heat and the marketable spear yield showed 1.1–1.3 times of that in the electrically heated wire system. The CO₂ emission and annual cost for 1 kg marketable spear production in the hot water heating system was obviously higher than those in the electrically heated wire system, however the small improvement of spear productivity was recognized in the hot water heating system. Scale of the wood pellet boiler in the present examination, prototype boiler, was excessive for the asparagus production in 9 m-length bed, and suitable scale of wood pellet boiler asparagus production should be installed in future.

Key Words: asparagus, electrically heated wire, hot water, LCA, wood pellet boiler
1. Introduction

Asparagus (Asparagus officinalis L.) is one of the most widely traded vegetables in the world. It belongs to the family Liliaceae and is a monocotyledous, rhizomatous, dioecious, herbaceous, and perennial plant (Tutin et al. 1980). The production of green asparagus in Japan is seasonally limited to the spring harvest period in the open fields and climate variability during this season lead to highly variable soil temperatures, resulting in a discontinuous asparagus spear production. Long-term production of asparagus is important because the demand for fresh asparagus in domestic markets has been steadily expanding. Cropping systems for long-term production have been established in southwestern Japan, such as mother fern culture (Jishi et al. 2013).

Because most of asparagus is imported from South American or South-east Asian countries in winter, the price is more expensive than that in summer. Domestic prices are approximately around 2000 yen/kg in winter, almost twice that of summer asparagus. Therefore, it is important to develop a new technique to produce a sufficient winter asparagus to meet the present and future demands of domestic markets. Fusekomi forcing culture (FFC) in a plastic greenhouses has been developed in northern Japan as a winter harvest cropping system (“fusekomi” means rootstock planting in Japanese) (Jishi et al. 2013). In this cropping system, one or two-year-old rootstocks grown in open fields are harvested just before winter and then transplanted into culture beds in a plastic greenhouse. Green spears are then produced from the planted rootstocks by warming the beds during winter (Haruyama et al. 1985; Koizumi et al. 2002; 2003; 2013).

Electricity and oil are typically used for warming the culture bed in FCC; the electrically heated wires are set at the base of the culture bed for warming, and some farmers use oil heaters for additional warming inside the plastic greenhouse. However, during FCC in winter, the oil or electricity heating lead to large costs and CO₂ emissions (Fujiwara et al. 2015).

To reduce costs and environmental impacts, an alternative heating system for the oil and electricity should be employed in today’s low carbon society. Some biomass are taken an attention for the material. Wood pellets are an important biomass fuel for reduction of CO₂ emission. It was reported that the gross calorific values of wood pellet was in the range from 19.7 to 26.8 MJ/kg (Yamada 2006). Characteristics of combustion of organic waste (Namba and Iida 2009) and pruned branch (Namba et al. 2010) were investigated. A new regional industrial model by local production and consumption of wood energy from rich forest resource are developed (Nagano et al. 2011).

Life cycle assessment (LCA) method has been established for the evaluation of CO₂ emission (Robert 2014). In the comparison with oil heater, there was a relation of trade off by the items of safe guard subject. In the evaluation by weighting, the environmental impact of pellet stove was smaller than that of oil fan heater by using LCA method (Ishizaka et al. 2007). As to CO₂ emission in the heating system with wood pellet, Taoka et al. (2009) evaluated CO₂ emission in the heating system with wood pellet in horticultural greenhouse by using LCA method, and they pointed out the wood pellet boiler system reduced more than 80% of CO₂ discharged in oil boiler system. CO₂ emission on burner production was omitted because of small amount in Taoka’s research.

In FFC system, it is necessary to warm inside of the culture beds planted asparagus rootstocks directly for spear emergence and heating by hot water obtained by the wood pellet boiler was examined. In the present examination, the asparagus spear production, heat supply to culture bed, CO₂ emission and cost were compared between hot water system using the wood pellet boiler and electrically heated wire for obtaining fundamental data of environmental friendly FFC system in Hokkaido.

2. Materials and Methods

All experiments were conducted in the Experimental Farm, Field Science Center for
Three culture beds (width: 0.8 m; height: 0.45 m; length: 9 m) with 3 different heating systems described below, containing 0.3 m-height soil with no fertilizer, were prepared in a plastic greenhouse. Heat insulators were set at the bottom and the side of the bed for effective warming.

Approximately 1.5 kg in fresh weight of two-year-old rootstocks of asparagus ‘UC 157’, collected on November 25, 2013, from the open field in the Experimental Farm. Four rootstocks were planted densely at 0.15–20 m depth from the soil surface, 3 sites in each culture beds on December 20, 2013 (Fig. 1). The planting density was 25 plants per m$^2$, standard in Fusecomi forcing culture (FFC).

2) Heating system

Three heating systems were employed in this experiment: 1) electrically heated wire for soil heating (EWS); 2) hot water (wood pellet boiler) for soil heating (HWS); and 3) hot water (wood pellet boiler) for soil and air heating (HWSA) (Fig. 1). The electrically heated wires, Noden cable for nursery production use, warmed the soil at the bottom of the culture bed at a temperature between 18 and 22°C by a thermo-controller, ND820 (Nihon Noden Co. Ltd).

The hot water heating system consisted of three components: 1) a wood pellet boiler; 2) a hot water storage tank (6000 Liter for soil warming and 1000 Liter for air warming inside the tunnel); and 3) a culture bed for asparagus spear emergence.

The wood pellet boiler was prototype, made by for this experiments (Kamide et al., 2010) and warmed water in two storage tanks above 50°C every morning, from 9 am to 1 pm. The main specifications of the used boiler were followings;

- Heat transfer area: 5 m$^2$
- Combustion chamber volume 0.24 m$^3$
- Combustion load: 1250 MJ/m$^2$
- Quantity of biggest combustion: 28 kg/h
- Heat value of pellet: 12.5 MJ/kg
- Rated burning capacity: 25 kg/h

Actual burning capacity of pellet was 15 kg/h when the present boiler worked. Wood pellet obtained from Ohtaki pellet factory, Date city, Hokkaido.

Hot water was circulated between the storage tank and the culture bed to warm the soil or air. Two lines were employed at different temperatures: a higher one for soil warming, in which hot water was circulated when soil temperature at 14 cm depth decreased below 20°C; and a lower one for air warming in a plastic tunnel when the air temperature
decreased below 15°C. A sensor of soil temperature was set at 15 cm-depth from the soil surface in each culture bed warmed by hot water (HWS and HWSA) and electricity (EWS). The sensor of air temperature was set at 30 cm-high from soil surface in culture bed of HWSA.

The culture beds were covered with a plastic sheet every night (4 pm – 8 am), to maintain the air temperature in the tunnel. In daytime, there was no sheet cover in a fine day, however the plastic sheet covered the culture bed in cloudy or snowy day.

3) Measurement

1) Temperature

Temperatures outdoors, inside the plastic greenhouse, inside the tunnel, and in the soil of culture bed at three different depths, (7, 14 and 21 cm from the soil surface), were measured by the thermocouples (T type) from January 6 to February 22, 2014 and data were recorded by a data logger, (midi LOGGER GL 820, GRAPHTEC, Japan).

2) Heat supplied to culture bed

Power consumption of electrically heated wire system was recorded by electric power meter (OMORON Co., Ltd, HK100) during the examination, January 6 to February 22, 2014.

The heat supplied to culture bed by hot water system (HWS and HWSA) with wood pellet boiler was calculated by multiplying of the temperature difference between inlet and outlet of hot water and the flow volume.

\[ Q = 4.19 \times (T_{in} - T_{out}) \times V \times \rho \]

Q: heat supplied from hot water [J/min],
Tin: inlet temperature of hot water [°C],
Tout: outlet temperature of hot water [°C],
V: flow rate of hot water [ml/min],
\( \rho \): density of hot water [g/ml].

The temperatures of hot water at inlet and outlet were measured by sheath type T thermocouples set in the hot water pipe. Flow volume was measured by flow meter (Regal Joint Co. Ltd, KSL-160L) in each examined bed for HWS and HWSA. Both hot water temperature at inlet and outlet and flow volume were record every minute for the calculation. The heat supplied to soil and air from hot water every minutes were accumulated for day’s data. In HWSA, there was two lines for warming soil and air, and flow meters were set in both lines of soil warming and air warming.

4) Yield of asparagus spear

The asparagus spears were harvested every day from January 6 to February 22, 2014. Spears were cut at the ground level when they grew to more than 24 cm. Spears weighing more than 8 g were recognized as marketable, but spears that weighted less than 8 g or were damaged, bent, or with open tips were defined as unmarketable. The number and weight of marketable and unmarketable spears were recorded every day.

5) LCA analysis

The life cycle assessment (LCA) method is currently common practice for evaluating the environmental impacts of investigated products or processes over their whole life cycle (encompassing, extracting, and processing raw materials, manufacturing, transportation, and distribution, use, re-use, maintenance, recycling, and final disposal) (Anna, 2014).

The life cycle inventory phase requires collecting input and output data. Input data necessary for processing MiLCA software, Ver. 1.1.2.50 (Japan Environmental Management Association for Industry) and IDEA Ver. 1.1.0 (National Institute of Advanced Industrial Science and Technology) were acquired by interviewing the company where the product was purchased. CO₂ emissions associated with transportation should be included downstream of the product system, however, some emission data were replaced by data for similar materials. Materials or equipment parts with a sufficiently small contribution to the LCA analysis were omitted (Table 1). Besides, amount of ash produced in the combustion of wood pellet was small, 1–2% in weight, and ash factor was omitted in LCA.

3. Result

1) Soil temperature

The soil temperature at 14 cm depth is the most important because spear buds in the root stocks exist near this depth. The average soil temperature at 14 cm depth remained at approximately 18–20°C
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The results showed that the soil temperature was highest at 21 cm depth and lowest at 7 cm from the soil surface. That at 7 cm depth changed varied substantially from 9°C to 20°C during the experiment because it was affected by the air temperature inside the tunnel. Such temperature

### Table 1: Input data in 3 heating systems for LCA.

| Item                        | Input data                              | Unit  | Lifetime (year) |
|-----------------------------|-----------------------------------------|-------|-----------------|
| Plastic for agriculture     | PVC film for agriculture                | 37.58 kg | 3               |
| greenhouse Steel pipe for tunnel | Steel pipe                             | 202.7 kg | 3               |
| Transport (from C. I. Kasei Company to Sapporo by rail cargo) | 1159 km | 1               |
| Disposal crushing treatment | 240.3 kg | 1               |
| EWS Special alloy           | 1 kg                                    | 3     |
| Special PVC                 | 0.5 kg                                  | 3     |
| Semiconductor               | 1.2 kg                                  | 3     |
| Electricity (Hokkaido Electric Power Company) | 157.1 kWh | 1               |
| Transport                   | 78.1 km                                 | 1     |
| (from Tsukubadenki Co., Ltd to Japan Nowden Co., Ltd. by regular sales car) | | |
| Transport                   | 1156 km                                 | 1     |
| (from Japan Nowden Co., Ltd to Sapporo by rail cargo) | | |
| Disposal crushing treatment | 1.1 kg                                  | 1     |
| Common Cast iron            | 1120 kg                                 | 15    |
| parts used Sheet metal tank | 630 kg                                  | 15    |
| by HWS Steel pipe           | 2700 kg                                 | 1     |
| and HWSA Electricity (Hokkaido Electric Power Company) | 2960 kWh | 1               |
| Transport                   | 137 km                                  | 1     |
| (from Asahi Setubi Co., Ltd to Sapporo by 1.5 t truck and 10 t truck) | | |
| Transport                   | 67.8 km                                 | 1     |
| (from Iwakura Corporation to Sapporo by 10 t truck) | | |
| Disposal crushing treatment | 1750 kg                                 | 1     |
| HWS Steel pipe              | 52 kg                                   | 15    |
| JIS specification socket    | 20                                      | 15    |
| disposal crushing treatment | 52 kg                                   | 1     |
| HWSA Sheet metal tank       | 210 kg                                  | 15    |
| steel pipe                  | 92 kg                                   | 15    |
| JIS specification socket    | 24                                      | 15    |
| transport                   | 137 km                                  | 1     |
| (from Asahi Setubi Co., Ltd to Sapporo by 1.5 t truck) | | |
| disposal crushing treatment | 92.5 kg                                 | 1     |

Some facilities with the life-time less than 1 year

in EWS and HWSA, and 15–18 °C in HWS (Fig. 2).

A significant temperature difference was observed among different soil depths. The difference in the average soil temperature between 7 cm and 21 cm depth was approximately 10°C for EWS and HWS, and approximately 5–7°C for HWSA system (data not shown). The results showed that the soil temperature was highest at 21 cm depth and lowest at 7 cm from the soil surface. That at 7 cm depth changed varied substantially from 9°C to 20°C during the experiment because it was affected by the air temperature inside the tunnel. Such temperature
transitions continued until the end of the experiment (soil temperature data at 7 and 21 cm depth not shown).

2) Air temperature

The minimum temperature outside the greenhouse decreased below −10°C on some days during the experiment, and reached a minimum of −18.2°C on February 7, 2014 (Fig. 3). Average air temperatures inside the greenhouse became below 0°C in some days during the study period.

Because freeze injury occurs in emerged spears when the air temperature is below 0°C, it is important to control the air temperature inside the plastic tunnel. The minimum air temperature of HWSA remained above 5°C inside the plastic tunnel, avoiding freeze injury in emerged spears (Fig. 3). However, the daily minimum air temperature in the plastic tunnel occasionally decreased to 0°C for EWS and HWS, which could lead to freeze injury.
The total heat supplied to the culture bed during the warming period, from Jan. 6 to Feb. 21, was 566,2152 and 5491 MJ for the EWS, HWS and HWSA, respectively (Table 3). The average daily heat was 12.5 MJ, 47.1 MJ and 122.0 MJ for the EWS, HWS and HWSA, respectively. The supplied heat in HWS and HWSA was 3.8 and 9.9 times of that in EWS.

Considering the marketable spear yield, the heat required for obtaining 1 kg marketable yield was 6980 MJ in HWS and 14262 MJ in HWSA during the examined period, 3.6 and 7.2 times that in EWS (Table 3).

The variation in daily supplied heat was recognized during the examination, especially HWSA heating showed 35 MJ in minimum on Feb. 12 and 250 MJ in maximum on Jan. 20 and Jan. 23 (Fig. 4). The difference in supplied heat between WASA and WAS was regarded as heat supplied for air warming. HWSA heating system provided relatively higher heat around Jan. 12 – 14, Jan. 16, Jan. 19 – 20, Jan. 22 – 23, Feb. 1 and Feb. 10 when minimum temperature outside and inside the plastic

### Table 2: Asparagus spear yield in 3 heating systems

| Heating system                  | Marketable spear yield |  | Heat supplied to soil and air (MJ/bed) | Heat/1 kg marketable yield (MJ/kg-spear) |
|---------------------------------|------------------------|--|---------------------------------------|------------------------------------------|
|                                 | Marketable spear yield |  | Full exam. day                        |                                         |
|                                 | (kg/plant)             |  |                                        |                                         |
| Electrically heated wire for soil (EWS) | 0.29                     | 566 | 12.5                                   | 1593                                    |
| Hot water for soil (HWS)        | 0.31                     | 2152 | 47.1                                   | 6880                                    |
| Hot water for soil and air (HWSA) | 0.39                     | 5491 | 122.0                                  | 14262                                   |

Period of full examination: 45 days (Jan. 6 – Feb. 21, 2014)
Area of bed: 7.2 m²

3) Spear yield

The spear yield was greatest with HWSA, 28.5 spears and 0.39 kg per plants (Table 2), and no significant difference was observed between EWS and HWS, 21.5 – 23.3 spears and 0.29 – 0.31 kg of spear weight per plant. Marketable ratio was 78 – 87% in three heating systems.

4) Heat supplied to soil and air

The temperature of hot water at inlet was 40 – 50°C in daytime because boiler produced hot water in every morning, and around 35°C in night time. Hot water flowed by pump only when soil and air temperature decrease below the set temperature, 20°C in soil and 15°C in air. The flow rate of hot water in pump-working showed 53 – 60 Liter/min in the warming line for soil and 49 – 53 Liter/min in that of air. There was a difference in the temperature between hot water in the pipe for soil warming and soil in culture bed because the pipe was set bottom of culture bed, and soil temperature was measured at 14 cm-depth from the soil surface. Temperature difference between the inlet and outlet showed 8 – 41°C in warming line for soil and 3 – 16°C in that for air in the present examination.

The total heat supplied to the culture bed during the warming period, from Jan. 6 to Feb. 21, was 566, 2152 and 5491 MJ for the EWS, HWS and HWSA, respectively (Table 3). The average daily heat was 12.5 MJ, 47.1 MJ and 122.0 MJ for the EWS, HWS and HWSA, respectively. The supplied heat in HWS and HWSA was 3.8 and 9.9 times of that in EWS. Considering the marketable spear yield, the heat required for obtaining 1 kg marketable yield was 6980 MJ in HWS and 14262 MJ in HWSA during the examined period, 3.6 and 7.2 times that in EWS (Table 3).

The variation in daily supplied heat was recognized during the examination, especially HWSA heating showed 35 MJ in minimum on Feb. 12 and 250 MJ in maximum on Jan. 20 and Jan. 23 (Fig. 4). The difference in supplied heat between WHS and WASA was regarded as heat supplied for air warming. HWSA heating system provided relatively higher heat around Jan. 12 – 14, Jan. 16, Jan. 19 – 20, Jan. 22 – 23, Feb. 1 and Feb. 10 when minimum temperature outside and inside the plastic
greenhouse decreased. Around these days, daily supplied heat in HWSA was obviously larger than that in HWS because of the air warming inside the plastic tunnel.

The air temperature in the plastic greenhouse affected the air temperature inside the plastic tunnel, asparagus growing space. Much amount of hot water was used for air warming inside the plastic tunnel because the specific heat capacity of air is 1.21 [KJ/m³•°C] (0.288[kcal/m³•°C] × 4.19 [KJ/kcal]), completely smaller than water in the soil.

5) Life cycle assessment (LCA) in 3 heating systems

CO₂ emissions associated with production, use and disposal of the three heating systems were calculated by using MiLCA (Fig. 5). The total CO₂ emissions from the production to the disposal were estimated as 99.5, 2720.1, 3389.9 kg-CO₂/bed for EWS, HWS, and HWSA, respectively (Table 4). Considering of the life time of the materials used in the present examination, annual CO₂ emissions was 78.1, 226.2 and 270.9 kg-CO₂/bed in EWS, HWS, and HWSA, respectively. The CO₂ emissions in HWS and HWSA were 2.9 and 3.4 times of that in EWS.

The annual CO₂ emissions for obtaining 1 kg marketable spear yield was 269.7, 723.4 and 703.6 kg-CO₂/kg-spear in EWS, HWS, and HWSA systems, respectively. The ratio of CO₂ emissions for obtaining of 1 kg-marketable spears in HWS and HWSA to that in EWS were 2.7 and 2.6.

6) Cost analysis in 3 heating systems

Asparagus produced in January was treated at the price of 2150 yen/kg, average of recent 10 years, in Tokyo Wholesale market (Agriculture & Livestock Industries Corporation, 2018). Income per bed was estimated 112, 120 and 151 thousand yen in EWS, HWS, and HWSA, respectively (Table 5). Considering of the life time of the materials used in the present examination, annual cost per bed in EWS was 76 thousand yen, and was obviously smaller than those in HWS and HWSA, 264 and 272
thousand yen, 3.5 and 3.6 times of EWS. The annual cost was the lowest in EWS and the highest in HWS. From view point of managing cost, EWS will be possible to continue, however, the estimated annual income in HWS and HWSA was smaller than the annual cost in each heating system.

For obtaining of 1 kg marketable spear production, the annual costs were calculated as 263, 843 and 707 thousand yen/kg-spear in EWS, HWS and HWSA, respectively. The ratio of cost for obtaining 1 kg-marketable spears in HWS and HWSA to that in EWS were 3.2 and 2.7, respectively.

### 4. Discussion

Wood pellet boilers are recognized as a heating method with low CO₂ emission. Some researches on renewable energy-use in agriculture production were conducted. Many wood pellet boilers have been introduced to horticulture production in greenhouses due to political support for establishing a low carbon society in Kochi Prefecture (Nagano et al. 2011).

Mabuchi et al. (2012) reported that greenhouse farmers have willingness to convert the wood biomass heating system from oil heating because of high price of oil and avoidance of global warming. Kayo et al. (2016) conducted a life cycle assessment of greenhouse gas emissions (GHG: CO₂, CH₄, N₂O) for a district heating and cooling (DHC) system using woody biomass and showed their reductions in Shiwa region, Iwate Prefecture. As to the cost in the glasshouse horticulture installed biomass heating system, much period will be needed for initial investment in some cases (Nakao et al. 2013).

The present study was a first trial to the feasibility of wood pellet boiler for asparagus cultivation during winter in Hokkaido. The present wood pellet boiler system made a suitable temperature condition for spear emergence in asparagus FFC. The soil temperatures obtained in 3 heating system were enough to grow spears from the buds initiated on the surface of rootstocks (Jishi et al. 2013).

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### Table 4 CO₂ emission in 3 heating systems

| Heating                                      | Marketable spear yield (kg/plant) | CO₂ emmision/bed (kg-CO₂/bed) | Annual* (kg-CO₂/bed/year) | CO₂ emmision / 1 kg marketable yield (kg-CO₂/kg spear) |
|----------------------------------------------|-----------------------------------|--------------------------------|---------------------------|-------------------------------------------------------|
| Electrically heated wire for soil (EWS)      | 0.29                              | 99.5                           | 78.1                      | 269.7                                                 |
| Hot water for soil (HWS)                     | 0.31                              | 2720.1                         | 226.2                     | 723.4                                                 |
| Hot water for soil and air (HWSA)            | 0.39                              | 3389.9                         | 270.9                     | 703.6                                                 |

*Considering the lifetime of materials used in the present examination (Table 1).

### Table 5 Estimated income and the cost in 3 heating systems.

| Heating                                      | Marketable spear yield (kg) | Estimated income* (1000 yen / bed) | Annual cost ** (x1000 yen) |
|----------------------------------------------|----------------------------|-------------------------------------|---------------------------|
| Electrically heated wire for soil (EWS)      | 0.29                       | 112                                 | 76                        |
| Hot water for soil (HWS)                     | 0.31                       | 120                                 | 264                       |
| Hot water for soil and air (HWSA)            | 0.39                       | 151                                 | 272                       |

Period of full examination: 45 days (Jan.6 – Feb.21, 2014)

*Estimated income; Marketable spear yield (kg/bed) x Spear price (2150 yen/kg). Average spear price was calculated from data (January) of Tokyo wholesale market.

**Annual cost was calculated from data described Table 1.
the plastic tunnel in HWSA, avoiding freeze injury in emerged spears even when air temperatures inside the greenhouse became below 0 °C. Such temperature condition in HWSA increased the spear yield in asparagus FFC.

The heat supplied per culture bed in HWS and HWSA showed 3.8 and 9.9 times of that in EWS. However, supplied heat for 1 kg marketable spear production in HAS and HWSA was 3.6 and 7.2 times of that in EWS and these ratios to HWS were smaller than those in the heat supplied per culture bed. Such reduction was contributed by the increasing of marketable spear production in hot water system, especially in HWSA. Same tendency was recognized in CO₂ emission and cost analysis.

The scale of used boiler was too large for the present asparagus FFC. The excess heat supply led to increase of CO₂ emission and production cost of asparagus spears. On the other hand, the present wood pellet boiler had a capacity to produce more amount of asparagus spears when FFC scale is expanded.

The economic analysis in horticultural production in the greenhouse with pellet boiler system has begun. Shiroma and Nasu (2008) reported the advantage of pellet boiler when oil price increase to more than 90 yen/liter in economic research and they pointed out the importance of stable price of pellet and establishment of wood pellet supply system. Sasaki (2014) pointed out the importance of enlightenment of the value in horticultural products by using bio-fuel for increasing the farmer’s income from 4 case studies.

Further evaluation will be needed by using more suitable sized boiler or by using larger scale equipment of FFC. Hot water use for many kinds of horticultural crops including asparagus FFC will be examined because hot water system will be able to transfer the heat to some greenhouse.

Acknowledgments

The authors thank Mrs. Shinji Ichikawa, Takao Kawai and Hideki Nakano, technical staffs in Hokkaido University, for their technical support for the examination, and also acknowledge the financial and academic support of the R-08-Init Project, entitled “Human-Environmental Security in Asia-Pacific Ring of Fire: Water-Energy-Food Nexus”, and the Research Institute of Humanity and Nature (RIHN), Kyoto, Japan.

References

Agriculture & Livestock Industries Corporation. (2018): Vegetable total and Aggregate Information System. https://vegetan.alic.go.jp/ Visited June 8, 2018.

Anna N, Robert S (2014): Comparison of LCA results of low temperature heat plant using electric heat pump, absorption heat pump and gas-fired boiler. Energy Conversion and Management 87; 647-652.

Fujiwara S, Araki H, Jishi T, Fujii M (2015) : Assessing of CO₂ emission reduction in Hot spring areas: Case study of for promoting utilization of unutilized energy in Nagareyama and Yubari hot springs, Hokkaido. J. Life Cycle Assessment, Japan. 8; 536-569.

Haruyama M, Ontuka T, Ikeda H, Muramatsu Y (1985): Harvesting within the year of green asparagus. Gunma Journal of Agricultural Research D, Horticulture. 1; 1-15.

Ishizaka K, Murayama K, Itsubo N (2007): Life cycle impact assessment for pellet stove. Journal of Life Cycle Assessment Japan. 3; 45-51. 2007.

Jishi T, Maeda T, Siga Y, Araki H (2013): Winter production of white asparagus from one-year old rootstocks by forcing culture. Acta Horticulturae 950; 27-32.

Kayo C, Ojimi R, Iwaoka M, Yasuda K (2016): Greenhouse Gas Emission. Reductions in a District Heating and Cooling System by using Woody Biomass. A study in Shiwa, Iwate Prefecture. J. Wood Science. 62;172-181. 2016

Kamide M, Yamakoshi Y, Oka Kishu (2010): Annual report: Outline of research results in 2009 and research plans in 2010, Hokkaido Industrial research Institute. Page 24, 64.

Koizumi T, Yamasaki H, Yamato Y, Hamano M, Takahashi K, Miura H (2002): Effects of cultivar, extent of cumulative chilling exposure,
age of rootstock and sex on growth of spear in asparagus forcing culture. Hort. Res. Japan. 1; 205-208.

Koizumi T, Kemmochi I, Yasuda Y (2003): Difference between male and female plant in growth one-year-old asparagus, yield and quality in forcing culture. Hort. Res. Japan. 4; 275-278.

Koizumi T, Ishizawa M, Yamada F (2013): Asparagus forcing culture using one and half-year-old rootstock by planting seedlings to field in spring. Bulletin of Gunma Agricultural Technology Center. 10; 47-50.

Mabuchi Y, Uemoto K, Nagano M, Nakagawa Y, Nasu S (2012): A modeling of farmer’s mind structure for utilization of woody biomass fuel. J. Japan. Soc. Water Policy and Integrated River Basin Manage. 1; 15-26.

Nagano M, Matsumura K, Takami S (2011): Building a new regional industrial model by local production and consumption of wood energy. Research bulletin, Kochi Univ. of Technology. 8; 187-194.

Nakao A, Yamamoto Y, Matsu T, Shiga T, Yoshida N (2013): Potential of carbon credit creation through replacing energy using facilities and utilizing biomass fuels in glasshouse horticulture. J. Japan. Soc. Civil Engineers. (G) 69; 371-382. 2013.

Namba K and Iida T (2009): Fuel and combustion Characteristics of organic waste. J. High Temp. Soc. 35; 76-80.

Namba K, Iida T, Sawai T (2010): Fundamental combustion properties of pruned braches of fruit tree for energy utilization. J. High Temp. Soc. 36; 25-30.

Taoka M, Fukada Y, Ito M, Nagano M, Nakano K (2009): Introduction of LCA for the Wood Pellet Heating System. Proceeding of 4th meeting of the Institute of Life Cycle Assessment, Page 242-243

Tutin T G, Heywood H V, Burges A N, Moore M D, Valentine H D, Walter S M, Webb A D (1980): Flora Europea, Volume 5, Alismataceae to Orchidaceae (Monocotyledons). Cambridge University Press, Cambridge, UK, pp.71-73.

Yamada A (2006): Fuel Characteristic of Pellet Fuel from Woody Biomass in Hokkaido. J. Hokkaido Forest Production Res. Inst. 20; 24-28.

Sasaki S (2014): The Use of Biomass Boilers in Horticulture Management: A Case Study of Maniwa-shi, Okayama Prefecture. J. Rural Problem 50; 55-59.

Shiroma S, Nasu S (2008): Economic analysis of horticultural production in the greenhouse installed biomass boiler in Kochi Prefecture (in Japanese title). Proc. Ann. Meet. Japan Soc. Civil Engineers. 7; 223-224.

キーワード

アスパラガス、電熱線、温水、LCA、ペレットボイラ

摘要

日本国内では秋季から冬季にかけての伏せ込み促成栽培によるアスパラガスに対して大きな需要がある。冬季、温室でのアスパラガス生産には、加温熱源として多量の石油や電気が必要であり、大量のCO2排出と高いコストを伴うことから、低炭素を有する代替加温システムが期待される。本研究では、北海道の冬季プラスチックハウスでアスパラガス伏せ込み栽培を行い、3種の加温システムを比較した。それらは①電熱線による土加温、②温水による土加温、および③温水による土と空気加温であった。温水は木質ペレットボイラにより製造された。いずれのシステムでも厳寒期においても14 cm 深の土壌温度は15〜20℃に維持された。厳寒期に外気が-18℃になった時でも、土壌と空気加温システムでは、若茎の伸長エリアが保温されたので凍害は発生しなかった。温水加温システムは従来型の電熱線加温システムよりも多量の熱量を供給しアスパラガス若茎の可販収量は電熱線加温の1.1〜1.3 倍に増加した。温水加温システムにおける1 kg 若茎生産のためのCO2 排出および所要コストは電熱線加温システムより明らかに大きくなったが、わずかな生産効率の改善が示された。本実験で使用したペレットボイラ（ブロトタイプ）は、伏せ込み栽培规模（9 m ベッド）に対して過剰な設備であり、今後アスパラガス栽培に適した大きさのペレットボイラの導入が期待される。