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Soilless Culture on Sloping Land

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ABSTRACT

In many parts of Japan, it is too hot in the summer to produce tomatoes in the greenhouse. An advantage of sloping fields in hilly and mountainous areas is that tomatoes can be grown in both summer and autumn. On hillside fields, tomato plants are commonly grown under rain shelters in which every row is covered by plastic sheeting because it is difficult to build a pipe-frame greenhouse, which is popular in Japan. However, exposed plants are sometimes damaged by wind, rain and pests. To avoid this problem, a sloped greenhouse was developed. The sloped greenhouse is typically made of inexpensive steel pipes which are frequently used as scaffolding in construction sites. To avoid problems such as lifting soil up and soil-borne diseases, when growing tomatoes on hillside fields, a soilless culture system suitable for use on sloping land was developed. In this system, in order to stop drainage from the lowest drip line, a type of drip tube providing drainage that would shut off below a certain pressure as well as check valves were inserted into the line. To save costs of installing and running the system, fertilizer injection and supply of nutrient solution to the plants were powered by water pressure only. We investigated the effects of installing a soilless culture system and a sloped greenhouse on tomato production. Tomato yields in a sloped greenhouse with the soilless culture system were exceedingly higher than those under conventional rain shelters. To test the effectiveness of such a greenhouse system during the winter season, the forcing culture of blueberry was investigated.

Keywords: greenhouse, hilly and mountainous area, irrigation, rain shelter, tomato

CONTENTS

INTRODUCTION

Hilly and mountainous areas occupy about 70% of the total land area of Japan. In history of a research of agriculture in hilly and mountainous area in Japan, there are some reports on crop yields and soil conservation of wheat, corn, potato, sweet potato, soy bean, buckwheat, and other cropping systems (Ito *et al*. 1953; Ichinohe and Kudo 1956). Nakamura *et al*. (1962) reported that making terrace farms on hilly and mountainous areas might promote farming efficiency by livestock power and the use of a tractor. However, nowadays, crops such as wheat, corn, and potato are hardly grown in these areas except for home consumption. Many sloping fields are not terraced in these areas. Vegetables, fruit trees and tea plants may be grown on sloping fields.

One of the advantages of hilly and mountainous areas is climate condition, especially cool temperatures in the summer, owing to high altitude. Maki and Tamaki (1986) and Tamaki *et al*. (1987) made classification maps of districts in Shikoku with respect to the climate and land location based to air temperature, precipitation, angle of inclination and soil properties, to determine cropping types of vegetables on sloping land or mountainous area in these districts. They showed the temperatures in August for some vegetables on the summer-autumn harvesting time were marginally high for open culture.

The advantages of hilly and mountainous areas are not only a cool temperature in summer. It is well known that the south slope is advantageous since it receives solar radiation in the cold season. The angles of incidence of solar radiation on hilly and mountainous areas are different from those on flat areas. The difference in the angles of incidence may be another advantage of hilly and mountainous areas. Shizuoka is famous for the production of high quality melons in Japan. The melons are grown in greenhouses that are called three-quarters greenhouse. In these greenhouses, terraces are made and melon plants are planted on cultivation beds in an east-west line. The beds are higher – like stairs – on the north-facing side of the greenhouse to increase light interception by plants. Miyamoto (1968) reported that solar radiation between melon plants planted in south-north lines in winter was 65% of that in east-west lines. Iwasaki and Kimura (1975) investigated micro-meteorological factors in a three-quarters greenhouse and reported that solar radiation transmissivity into the greenhouse was about 70% all year round.

Sato (1967) investigated sunshine exposure and shade in various terraces, diurnal and seasonal changes and latitudinal variation of insulation on the terraces and slopes. He concluded that slopes had the advantage of receiving more

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Invited Mini-Review

Fig. 1 Hilly and mountainous area in Shikoku area in Japan.

Fig. 2 Tomato cultivation under rain shelters on sloping land. (Reprinted from **Higashide** (2004) *Research Journal of Food and Agriculture* **27**, 34-38, with kind permission of Agriculture, Forestry and Fisheries Technical Information Society).

solar radiation than terraces in all directions, except north. Fujiwara and Abe (1973) reported the solar radiation and climate condition of some slope areas in Tohoku district, supporting Sato's (1967) data that the south slope had advantages by receiving solar radiation. Kurose *et al*. (1991) developed an estimation model for the evaluation of radiation conditions as potential incoming solar energy by using the elevation data from the National Land Numerical Information. They also supported the advantage of south slopes and concluded that farms in mountainous regions were located in a high-isolation area, defined by the model.

Especially in the Shikoku area, some people are living in hilly and mountainous areas and a proportion of the land found on steep slopes is higher than the average in Japan (**Fig. 1**). Masubuchi (1997) reported that new trends of agriculture such as the establishment of horticultural centers and opening up of new markets were developed in sloping land agriculture in the Shikoku area which faces serious problems such as depopulation, aging farmers and abandonment of cultivation. He also pointed out that to promote sustainable development of regional agriculture, identification and marketing of special local products, a price compensation program, introduction of facilities and machines on a rental basis, reduction of burdened drudgery work and development of infrastructure for conserving the environment would be important. Kawauchi *et al*. (2003) established labor-saving and year-round culture of leafy vegetables such as lettuce and cabbage in hilly and mountainous slope areas.

TOMATO PRODUCTION IN HILLY AND MOUNTAINOUS AREAS

In Japan, tomatoes are not produced outdoors because of too much rain that causes some plant diseases. However, in many parts of Japan, it is too hot in the summer to produce tomatoes in the greenhouse. An advantage of sloping fields in hilly and mountainous areas is that they can grow tomatoes in both summer and autumn, owing to cooler temperatures in the summer. Cultivation of summer and autumn-harvesting tomato under rain shelters was started on hilly and mountainous area in Gifu, central Japan (Futatsudera *et al*. 1976). The cultivation of tomato under rain shelters avoided some plant diseases, and increased yields and the harvesting term compared to outside cultivation. Yamamoto *et al*. (1983) reported the yield under rain shelters increased 11-36% compared with that on outside fields. The cultivation and its research spread all over the hilly and mountainous areas of Japan: Tohoku (Tomita *et al*. 1981; Takahashi and Takai 1983) and Kyushu (Yukitake 1982).

On steep hillside fields, tomato plants are commonly grown under rain shelters in which every row is covered by plastic sheeting because it is difficult to build a pipe-frame greenhouse, which is popular in Japan (**Fig. 2**; Higashide 2004). However, there were some problems in tomato production under simple rain shelters. The facility of the rain shelters and plants were often damaged by strong wind such as typhoons. Exposed plants were sometimes damaged by wind, rain and pests. Effects of agricultural chemicals were decreased by rain. Rain also increased fruit cracking and decreased fruit quality. Yield and quality of products sometimes decreased and were unstable.

Two other serious problems in producing tomatoes on a sloping field occurred. One is that the soil continuously but slowly migrates down-slope and requires hard labor to bring it back up into the field before planting crops. Bringing back soil imposed a burden on aging farmers (Inooku *et al*. 2003). This happen also in the greenhouse. The other problem was soil-borne diseases caused by *Pseudomonas* and *Fusarium*. In some of these areas, tomatoes had been cultivated for more than 30 years. These diseases broke out every year in some fields even though soil disinfectant was injected, and were pointed out by Sakoda *et al*. (2006) to be one of the major problems for farmers in hilly and mountainous areas.

DEVELOPMENT OF A SLOPED GREENHOUSE

To produce vegetables on steep fields in hilly and mountainous areas stably, a greenhouse suitable for these areas is desired. Iriguchi *et al*. (1995) developed a sunshine-amplified, windproof structure greenhouse which can obtain an amount of solar radiation and is resistant to wind by effectively using stair-fields on south-facing hillsides. They reported that the number of cut gerbera stems in the greenhouse increased 10-20% in winter compared with that in the traditional-type, north-south orientation greenhouse.

To build on steep fields both terraced and not terraced, a sloped greenhouse was developed (Nagasaki *et al*. 2001; Nagasaki 2002, 2005) which was made of inexpensive steel pipes, 48.6 mm in diameter, which are frequently used as scaffolding in construction sites. The greenhouse has a flat roof that is almost parallel to the field (**Fig. 3**; Higashide *et al.* 2005b) but it is possible to build a greenhouse to match the crooked shape of a hillside field.

The greenhouse has windows on all sides, which are capable of rolling up near the roof. Ventilation is good because of the greenhouse structure and the presence of anabatic winds (Shibata *et al*. 2003). The cost (~¥3,000 m^{-2}) of the materials of a sloped greenhouse was almost the same of a piped-frame greenhouse, which is popular in Japan. Popular type greenhouses are made of steel pipes with 25.4 mm diameters. Sloped greenhouses are stronger than popular greenhouses because of the structure and strength of structural materials.

Fig. 3 Sloped greenhouse. (Reprinted from **Higashide *et al.*** (2005b), *Acta Horticulturae* **691**, 243-248, with kind permission of the International Society for Horticultural Science, http://www.actahort.org).

IRRIGATION ON SLOPING FIELD: PROBLEMS AND SOLUTIONS

The technique used for irrigation on sloping lands is more important than on flat areas. Hasebe (1971) investigated a distribution of irrigation by sprinklers on sloping land. He proposed that a sprinkler riser should be planted at right angles to the slope and improved the uniformity of sprayed water. Many studies have been made concerning drip irrigation on sloping land (Yamamoto *et al* 1977; Anyoji and Wu 1985, 1986a, 1986b). They pointed out that the arrangement of pipes depended on the level and features of the land, and that water pressure are important for irrigation on hilly and mountainous areas. They also showed the way of designing the sub-main manifolds and the lateral lines in a drip irrigation system. Morinaga *et al*. (2004a) developed a novel growing system using drip irrigation and liquid fertilization system combined with year-round plastic mulching, expected to increase the quality and stability of fruit production of satsuma mandarins in hilly and mountainous areas. They investigated characteristics of different drip irrigation tubes, the relationship between tube setting and water efflux, and the index of watering and fertilizer management. Morinaga *et al*. (2004b) reported that fruit quality was well controlled through the system and about 17.5 hr/10a/year of labor time was saved since labor for weeding and fertilizer applications was saved.

The production of vegetables compared to produce other crops such as as fruits, precise uniformity of irrigation is desired. Outflow from the lower part of the lines is one problem of drip irrigation on sloping fields. To prevent the outflow, Kawashima *et al*. (2000) developed a drip irrigation system which added an electricity valve in the lowest part of lines, a reservoir tank, a feed tank and a pump. Every time water was supplied, the remaining water in pipes was removed and stocked in the reservoir tank and was pumped up the feed tank before water supply. However, the modification of drip irrigation required extra facilities and running costs.

Higashide *et al*. (2005a) investigated outflow from the lower part of the lines and dissolution of the outflow in drip irrigation in sloping lands. We tested two kinds of drip tubing in a sloped greenhouse in which the 20° gradient and the difference in elevation between the highest and the lowest lines was about 4.5 m. In one type of tubing, if the water pressure fell below the shut-off pressure, the flow from the drippers stopped and the water stayed within the tubing. When the main water valve was open, the flow rate was almost the same in each dripper line because both tubings included an internal pressure-compensating mechanism to maintain a constant flow rate over a wide pressure range. However, the amount of leakage from the lowest line after closing the water valve differed depending on the type of tubing. With tubing that did not have a shut-off mechanism, outflow from the lowest line continued for 12 min; the total excess volume was 211 mL emitter^{-1}. The yield on higher positions in the sloped greenhouse was less than that on the lower positions because of insufficient water supply (Higashide 2006b). With tubing that had a shut-off mechanism and when check valves were inserted into the main line to divide the dripper lines into sections, the outflow from the lowest line in the greenhouse stopped even faster (in 0.33 min); the volume was only 7 mL emitter^{-1}. We showed the dissolution of the outflow by the tubing which had a shut-off mechanism and arrangement of the lines.

SOILLESS CULTURE SYSTEM SUITABLE FOR USE ON SLOPING LAND

To avoid problems such as lifting soil and soil-borne diseases, there was a demand for a soilless culture system suitable for use on sloping land when growing tomatoes on hillside fields. There are many types of soilless culture systems for a flat area but no system for sloping land. Generally, a soilless culture system requires high installation and running costs. To save costs, some soilless culture systems were developed. Chikanori *et al*. (1982) developed a soilless culture system consisting of Styrofoam fish boxes filled with rice husk; the cost of the material was ¥800 m^{-2}. Sakuma (2001) developed a soilless culture system to grow leafy vegetables such as spinach and spinach mustard, and which did not require electricity.

A soilless culture system suitable for use on sloping land was developed to avoid problems experienced on hillside fields (**Fig. 4**; Higashide *et al*. 2005b). To save installation and running costs, as an alternative solution for power supply and collection, we used water pressure and inclination of a land in hilly and mountainous areas in the soilless culture system. The soilless culture system suitable

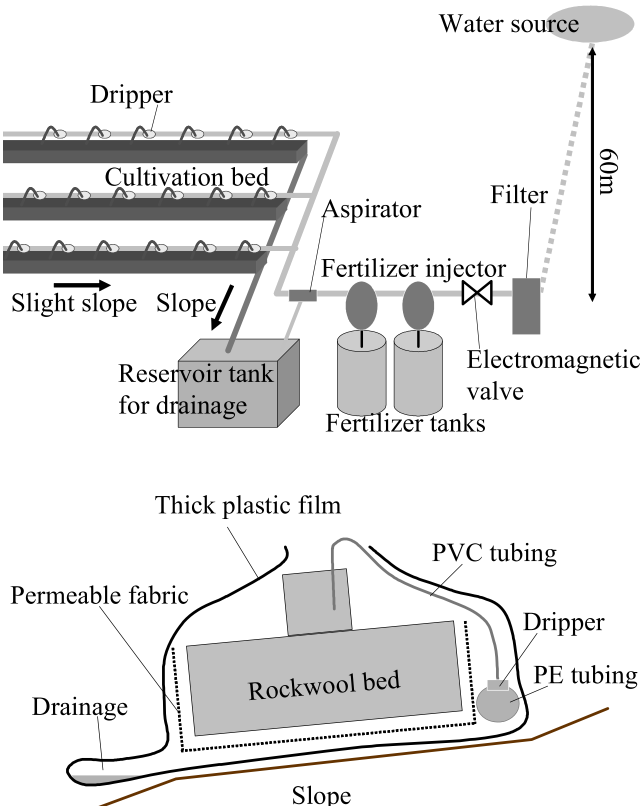

Fig. 4 Soilless culture system for sloping land. (Reprinted from **Higashide *et al.*** (2005b), *Acta Horticulturae* **691**, 243-248, with kind permission of the International Society for Horticultural Science, http://www.actahort. org).

for sloping land was constructed from individual drippers that had mechanisms of pressure-compensated and shut-off inserted into polyethylene blank tubing, fertilizer tanks, a disk filter, fertilizer injectors, a drainage reservoir, an aspirator, an electromagnetic valve, and a time switch. The nutrient solution supply and injection of fertilizer were powered only by water pressure, without electric power or a pump. The cultivation beds were made of rockwool or bark compost wrapped in a permeable fabric sheet to prevent root penetration and in thick plastic sheeting; it was placed directly on the ground. Nutrient solution that was not absorbed by the plants drained into the lower side of the thick plastic sheeting. Cultivation beds were placed along contour lines. The unabsorbed nutrient solution drained within the plastic sheeting along the slope of the ground into a reservoir tank. Used nutrient solution from the reservoir tank was mixed with fresh solution for re-use by means of an aspirator. Kasahara *et al*. (2005) reported that the mixing ratio of used to fresh nutrient solution in the soilless culture system was 22% at 0.31 MPa of water pressure. In the system, the mixing ratio of nutrient solutions was kept at about 20% reused drainage water obtained from the reservoir tank plus about 80% fresh solution. We thought that the resulting change in nutrient composition was smaller than that which occurs in a recirculating nutrient film technique system. The system did not require pumps, a large tank, electrical conductivity or pH sensors for monitoring nutrient solution, or an expensive controller, and the total cost was only about ¥1,160 m^{-2}. The system did not use electric power except for the electromagnetic valve and timer, which are exchangeable for battery-powered.

Generally, growers who installed a soilless culture system tend to control nutrient solution precisely to increase yield and fruit quality per costs of fertilizers. Feedback control based on drainage flow match the nutrient solution supply to the plants' demands (Gieling *et al*. 2000; Higashide *et al*. 2002). However, automated feedback control systems are expensive for small farms, where the growers prefer not to invest much money in soilless culture systems and greenhouses.

The soilles culture system for sloping land was specifically aimed at growers in hilly and mountainous zones, where the area of field per grower was smaller than that in other zones in Japan. Therefore, saving costs were more important than precise control of solution supply. Higashide *et al*. (2007a) investigated a reasonable method for small and aging growers, in order to control of nutrient solution supply to tomato plants grown in the system. We compared two methods of controlling the nutrient solution supply. As one method, solution was supplied whenever the accumulated solar radiation reached a set point. As the other method, solution supply was controlled by a 24 h time switch. Fruits yields were similar in the two methods of supply control. Therefore, controlling the nutrient solution supply by a time switch can be as effective as the control based on cumulated solar radiation. Besides, the time switch method may decrease the installation cost of the soilless culture system.

CULTIVATION OF CROPS BY THE SOILLESS CULTURE SYSTEM FOR USE ON SLOPING LAND

The impact of installing the soilless culture system and a sloped greenhouse in tomato-growing farms was investigated in Shikoku area, Japan (Higashide 2006a; Higashide *et al*. 2007b). We compared tomato cultivation using a sloped greenhouse (**Fig. 5**, Higashide 2006c) and the soilless culture system with cultivation under the conventional rain shelters for 4 years. Tomato plants were transplanted at the end of April to the beginning of May in the sloped greenhouses, at the end of May to the beginning of June under the conventional rain shelters. Cost of materials of the greenhouse and the soilless culture system were ¥3,000 m^{-2} and ¥1,160 m^{-2}, respectively.

The number of times using insecticides in the greenhouse with an insect screen were lower than that under the conventional rain shelters. There was no consistent tendency in the number of times germicides were applied in the greenhouse compared with that under conventional rain shelters. The harvesting terms of fruits were from July to November under the conventional rain shelters, from June to December in the greenhouse. Tomato yields in the sloped greenhouse with the soilless culture system were exceedingly higher than those under the conventional rain shelters (**Fig. 6**). Compared with the greenhouses, tomato yields under the conventional rain shelter demonstrated sharp fluctuations because of damages due to typhoon or plant diseases. Sakoda *et al*. (2006) reported that installing the sloped greenhouse and the soilless culture system increased the tomato yield and income of the grower, although the installation cost more than that of a conventional rain shelter.

To use a sloped greenhouse and a soilless culture system all year round, some other crops grown in the greenhouse during winter season were researched. Fruit trees grown in a greenhouse were developed and have spread throughout Japan (Kamota 1990). Cultivation area of blueberry plants (*Vaccinium corymbosum* L.) is increasing in Japan. However, there are few reports about a forcing culture of blueberry grown in a greenhouse.

Blueberry is a deciduous fruit tree which has a dormant period and requires exposure to cold temperature to break dormancy. Aoki *et al*. (1995) and Aoki and Ueda (1996) reported that a cold storage of blueberry plants brought the date of flowering forward. Suzuki and Kawata (2001) reported that an advanced date of flowering of blueberry plants

Fig. 5 Tomato plants grown in the soilless culture system for sloping land. (Reprinted from **Higashide** (2006c) *Survey of Agricultural Technology. Vegetable* **12**, 143-149, with kind permission of the Rural Culture Association).

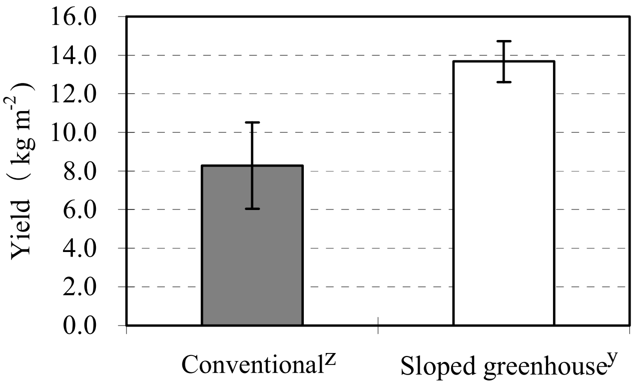

Fig. 6 Effect of installing a soilless culture system and a sloped greenhouse on tomato yield on a hillside field. (Reprinted from Higashide *et al*. 2007a, *Acta Horticulturae*, in press (http://www.actahort.org) with kind permission of the International Society for Horticultural Science).

brought a correspondingly advanced harvesting date. There were reports that blueberry plants grew well in acid soil (Tamada 1997a) and their growth increased by ammonium nitrogen rather than nitrate nitrogen (Tamada 1997b). We felt that the application of a soilless culture for growing blueberry plants would effectively avoid difficulties in soil management.

Higashide *et al*. (2006) investigated forcing culture of blueberry to use the greenhouse and the system effectively during the winter season. We transplanted blueberry plants in containers filled with a peat-moss and supplied nutrient solution by the soilless culture system suitable for sloping land. In this forcing culture, the plants experienced a term of cold temperature when placed outdoors in hilly and mountainous area (about 300 m above sea level) in Shikoku area until the beginning of February. Plants were exposed to a cumulative of more than 1200 hrs hours below 7°C at the beginning of February. Then, the plants were brought into a heated greenhouse near the field. Flowering of plants in the forcing culture started at the end of February, which was 35–40 days earlier than that under standard culture in flat area. We could have brought the plants into the greenhouse earlier than the beginning of February because they had received sufficient cumulated hour of exposure to low temperatures.

In order for blueberries to set fruits, pollinators are required. Ye *et al*. (2004) reported that heating accelerates the flowering date and subsequent fruit setting in blueberries, and is improved by pollination with bumble bees (*Bombus (bombus) terrestris L*.). We also employed bumble bees in the forcing culture. The harvesting from plants in the forcing culture started at the end of April, which was about 35 days earlier than that in the standard culture. The shipped fruits from the forcing culture had a 1.5-2.2 times higher price than that from the standard culture during other seasons. We believe that the forcing culture of blueberry using the greenhouse and soilless culture system is a promising culture method in hilly and mountainous areas.

In addition to tomato and blueberry, other crops have also been grown in the soilless culture system such as melon in summer and celery in winter (Higashide 2006c). These plants could grow well in the system without any trouble.

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JAPANESE ABSTRACT

本総説では、傾斜地におけるトマト栽培の問題を解決するために開発された傾斜ハウス及び傾斜地用養液栽培システムの概略とその導入効果等について紹介する。日本の夏は非常に高温となるため、多くの地域でハウス内におけるトマト栽培が困難となる。これに対し、中山間傾斜地域の利点のひとつとして、夏秋季でもトマト生産が可能なことがあげられる。わが国で広く用いられているアーチ型パイプハウスを傾斜した圃場に建設することは困難である。このため、傾斜地では畝ごとにプラスチックフィルムで作物上部を被覆する簡易雨よけによってトマト栽培が行われている。しかし、簡易雨よけ栽培では、天候や害虫による被害が生じることも多い。このような問題を回避するために、建設現場で用いられる安価な足場鋼管を材料とする傾斜ハウスが開発された。また、傾斜地のトマト栽培で問題となる土揚げ作業や土壌病害などを回避するために、傾斜地用の養液栽培システムが開発された。傾斜地用養液栽培システムでは、最下部の給液ラインからの液漏れを防ぐため、水だれ防止機能付の点滴資材を用い、給液管の途中に逆止弁が設置されている。また、導入コストとランニングコストを下げるため、液肥の混入や作物への培養液の供給の動力源として水圧が用いられる。この養液栽培システムと傾斜ハウスとをトマト生産者に導入した場合の効果が調査されており、トマトの収量は慣行の簡易雨よけ栽培に比べて、傾斜ハウス及び養液栽培システムを導入した場合に著しく多くなることが明らかになっている。また、冬季における傾斜ハウス及び養液栽培システムの利用法のひとつとしてブルーベリーの促成栽培が検討されている。