Soilless Culture on Sloping Land

Tadahisa Higashide

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 on sloping land or mountainous area in these districts. They showed the temperatures in August for some vegetables on sloping land or mountainous area in these districts. They concluded that slopes had the advantage of receiving more 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

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

CONTENTS
INTRODUCTION................................................................. 30
TOMATO PRODUCTION IN HILLY AND MOUNTAINOUS AREAS ................................................................. 31
DEVELOPMENT OF A SLOPED GREENHOUSE......................... 31
IRRIGATION ON SLOPING FIELD: PROBLEMS AND SOLUTIONS ................................................................. 32
SOILLESS CULTURE SYSTEM SUITABLE FOR USE ON SLOPING LAND ................................................................. 32
CULTIVATION OF CROPS BY THE SOILLESS CULTURE SYSTEM FOR USE ON SLOPING LAND ................................................................. 33
ACKNOWLEDGEMENTS ............................................................. 34
REFERENCES .............................................................................. 34
JAPANESE ABSTRACT .............................................................................. 35
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.

**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 anaerobic winds (Shibata et al. 2003). The cost (~¥3,000 m²) 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.
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/ha/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

![Diagram of soilless culture system for sloping land.](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 re-used 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 soilless 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 green-

---

**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 April, which was 35–40 days earlier than that under standard culture in flat 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 April, 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 produced 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.

ACKNOWLEDGEMENTS

The development of the soilless culture on the sloping land was accomplished as parts of a research project of National Agriculture and Food Research Organization: “Establishment of value-added production system for vegetables on sloping lands (2002-2007)”. We thank Mr. M. Tani and Mr. H. Kubo, Mr. O. Kubo and their families for renting us a field and for their cooperation in the experiment.

REFERENCES

* In Japanese
** In Japanese with English abstract


Anyoshi H, Wu IP (1985) Study on the design of drip lateral lines. Transaction Society of Irrigation, Drainage and Reclamation Engineering 120, 11-17**

Anyoshi H, Wu IP (1986a) Study on the design of submain manifolds in drip irrigation systems. Transaction Society of Irrigation, Drainage and Reclamation Engineering 121, 91-94**

Anyoshi H, Wu IP (1986b) Study on the design of irrigation lines in a submain unit in drip irrigation systems. Transaction Society of Irrigation, Drainage and Reclamation Engineering 121, 17-21**


Fujiwara T, Abe H (1973) Change in meteorological condition by altitude and direction in sloping land. Bulletin Tohoku National Agricultural Experimental Station 16, 3-10**


Hasebe J (1971) A study on the improvement of uniformity of sprayed water distribution in sprinkler irrigation on slope land. Bulletin of Tokai-Kinki National Agricultural Experimental Station 22, 5-134**

Higashide T (2006a) Protected cultivation of tomato in a sloped greenhouse by a hydropions system suitable for use on sloping land. Proceedings of Vegetable and Tea Science 3, 79-84**

Higashide T (2006b) Effective use of characteristics of a sloping field in hilly and mountainous area for a soilless culture system and cultivation of tomato. Agriculture and Horticulture 81, 562-570*


Higashide T, Aoki N, Kinoshita T, Ikuki T, Kasahara Y (2006) Forcing culture of blueberry grown in a container using a hydropions system suitable for use in hilly and mountainous areas. Horticultural Research (Japan) 5, 303-308*


Ichinohe S, Kudo K (1956) Studies on the control of soil erosion. II. Effects of contour cultivation. Bulletin of Tohoku National Agricultural Experimental Station 8, 46-54*


Ito K, Matsuoka K, Kawakami K (1953) Studies on the cropping system on the hillside farm. I. In relation to the control of structure runoff and erosion. Bulletin of Shikoku National Agricultural Experimental Station 23, 39-42*


Masubuchi R (1997) Regional characteristics and reorganization of agriculture in hilly and mountainous areas. Bulletin of Shikoku National Agricultural Experiment Station 1, 10-17**

Miyamoto J (1968) Study on solar radiation in a greenhouse. Agriculture and
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、秋や冬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、傾斜地では戸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屋根によってトマト栽培が行われていた。しかし、簡易屋根栽培では、病害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、建設計画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も回避するために、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、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、導入コストをランニングコストを下げるため、液肥の混入や作業への導入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屋根栽培に比べて、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。