Industrial Cultivation Using the Latest Sandponics System

Masato BABA* and Naoki IKEGUCHI

Sandponics is a unique cultivation system self-developed in 1970s ahead of the world based on the principle that leads to a sunlight-based modern plant factory using a soil-free and greenhouse facility. Since the start of its development, the system has maintained competitive advantages of the high quality of products. Improved recently, the system now enables simple water supply management, reducing facility cost and further enhancing quality. We cultivated tomatoes, the most marketable vegetable, as a model, and successfully created unconventional tomato fruits characterized by their volume and proper sweetness and receiving a high reputation, "tasty." Sandponics is expected to be a promising cultivation system that satisfies the demand for high quality vegetables both inside and outside Japan.

Keywords: agricultural business, cultivation system, Sandponics, taste, quality assurance

1. Introduction

Vegetable production in Japan is decreasing due to aging of farmers and a reduction in the farming population. Domestic vegetable shipments have dropped by 21.4% over 20 years from 13.63 million tons in 1993 to 10.72 million tons in 2012. Wholesale prices, which reveal the market size, also fell by 29.2% from 2.9893 trillion yen to 2.1182 trillion yen (Source: Statistics Bureau, Ministry of Internal Affairs and Communications). Both the domestic and international situation surrounding the Japanese agriculture have become severe, as seen in the increasing need to strengthen the international competitiveness of Japanese agricultural products alongside the discussions of Japan joining the Trans-Pacific Strategic Economic Partnership Agreement (TPP). However, the relaxation of Agricultural Land Act made in 2009 enabled corporations to participate in agricultural business encouraging the appetite for agribusiness.

Sumitomo Electric Industries, Ltd. commenced development of the original Sandponics system in the 1970s, anticipating the necessity of invigoration of domestic agriculture. The underlying philosophy here is the industrialization of agriculture[(1),(2)], and its aim was to contribute to the recovery of Japanese agriculture, which was already on a declining trend, by developing it to a business level equal to industry. This should be achieved through introducing production management systems using devices and systems developed by the industrial area. The industrialization of agriculture is also expected to help build a business model that can be expanded into overseas markets by protecting its technologies through registering them as intellectual property, in the same manner as industry.

This paper reports the latest research results concerning the Sandponics system, which Sumitomo Electric has developed towards the industrialization of agriculture.

2. Sandponics – Features and Challenges

The Sandponics system is a cultivation system that uses sand as primary medium. Sumitomo Electric exclusively developed this system and commenced sales in 1979. The Sandponics system is one of the various greenhouse-based agriculture systems designed to improve agricultural productivity through enabling year-round farming in a controlled environment. It is also one of the earliest models of today's "natural light plant factories." The system consists of an air-permeable bed filled with sand compliant with Sumitomo Electric's own standards, a dripping water supplier, and a liquid fertilizer dilutor. This was the epoch-making system that allowed stable agricultural production eliminating the unstable nature of ordinary soil (**Fig. 1**)[(3)].

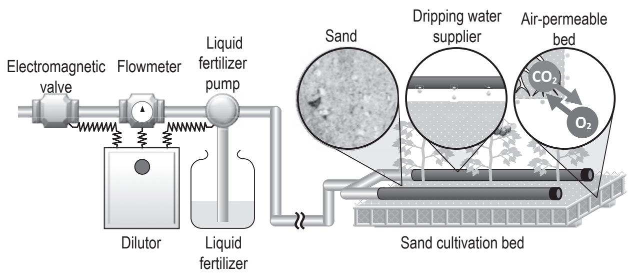

Fig. 1. Configuration of the Sandponics System

For Sumitomo Electric to enter the agricultural business, our unique Sandponics system must present sufficient superiority against its competitors, as well as offering unique added-value. However, non-soil-based agriculture is no longer novel. In natural light plant factories (highly advanced greenhouse agriculture systems) modeled in Holland, the world's hydroponic leader, light-weight and disposable cultivation media with high water retention capabilities, such as Rockwool, are actively employed to maintain environmental stability. Based on this trend, we have reviewed the features of the Sandponics system, below.

Table 1. Comparison of Agricultural Systems

	Hydroponics			Soil
	Sandponics (Sand)	Light-weight media (Rockwool, palm fiber, etc.)	Pure hydroponics (No medium used)	
Soil moisture tension effects (Taste improvement effects)	Good*1	Poor	Poor	Average
Stability of media quality	Good*2	Good	–	Poor
Deterioration due to continuous cropping	None (No media change required)	None (Media change required every single or two cropping)	None (Disinfection required)	Yes
Soil-borne diseases	None	None	None	Yes
Media disposability	Good	Poor	–	Good
Weight of media required to grow a single tomato plant	Poor (15.2 kg)	Good (0.4 kg)	Good (0 kg)	–
Cultivation container costs	Poor (High bearing capacity)	Good (Low bearing capacity)	Good (Low bearing capacity)	Good (Not required)

*1 Water suction by the plants can be flexibly controlled
*2 Sumitomo Electric standardized sand selection criteria (particle size, pH, etc.)

Table 1 shows a comparison of the different cultivation systems. The physical and chemical features of the medium, such as sand and Rockwool, are important factors in characterizing the cultivation systems. A medium is expected to have sufficient water retention capacity (almost equivalent to its cavity space) and soil moisture tension (water absorption power) uniformly across its mass, as well as little deterioration over the time. It is also expected to be light-weight, low costs, and easy to obtain and discard. The most significant feature of sand is that it has a greater soil moisture tension compared to Rockwool. For this reason, the moisture in the sand is less absorbed by the plants compared with Rockwool, resulting in the product having a better taste due to the condensed flavors through less water in the product. Sand also exhibits a stable media quality due to the low amount of deterioration over time and its resistance against pest proliferation. Sand is essentially a single-grained structure formed by an aggregation of independent particles. This feature of sand makes maintenance of the medium simple, compared to a crumb structure medium, such as soil, which is an aggregation of clusters made of various particles. In other words, the sand cultivation bed is easier to keep healthy. Furthermore, sand is abundant in the natural world and easy to obtain. It is also easier to discard compared with Rockwool, which is categorized as an industrial waste. However, sand requires highly accurate moisture control as it has less than half the water retention capacity compared to Rockwool. Sand is also 20 times heavier than Rockwool and therefore a cultivation bed to support the medium becomes more costly.

Taking into consideration these benefits and disadvantages, we have significantly improved the Sandponics system.

To assess the system improvements, we used tomatoes as the test plant due to the following advantages:

(a) Marketability
- (1) The largest scale in the domestic market of vegetables and fruits (205.1 billion yen by Statistics of Agricultural Income Produced 2011) and still rising.
- (2) Also the largest in the world market (largest among all the vegetables by FAO 2010) and still rising.
- (3) The annual consumption in Japan is 48% of the world average, indicating an area of potential growth.
- (4) The estimated revenue by producer is the largest among all vegetables (8.5 million yen per year, calculated by Sumitomo Electric).

(b) High added value
- (1) Easy to create taste differentiation and there is an obvious positive correlation between sugar content and price.
- (2) Multiple control/management factor areas involved in the growing procedure.
- (3) Rise in sugar content can be expected by using the Sandponics system.

(c) Model plant for vegetable business
- (1) The cultivation techniques acquired can be easily applied to other plants because the growing procedure involves leaves, flowers, and fruits.

3. Improving Sandponics

The features of Rockwool, the competitor medium of the Sandponics system, is easy watering and low facility costs due to its light weight. The first improvement we made was simplification of irrigation by identifying the optimum moisture conditions.

Sand requires highly accurate irrigation control for stable crop production, while Rockwool only needs moderate control. Our Sandponics crop production experiments showed failed and successful results. In the failed cases, plant growth was halted by accumulated ammonia contained in the Sandponics fertilizer (**Fig. 2A**), while in the successful cases, the ammonia was resolved

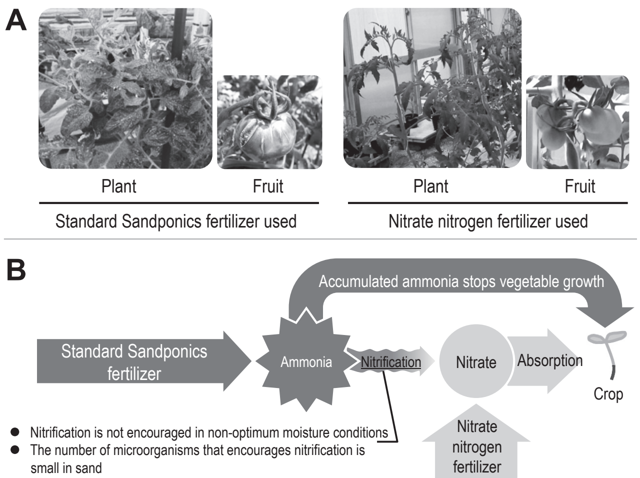

Fig. 2. Abnormal Growth Symptoms (A) and Conceptual Chart of Cause (B)

into nitrogen by oxidation, preventing the accumulation of ammonia (**Fig. 2B**). The optimum moisture value was determined by analyzing these cases, and we controlled irrigation to maintain this moisture value. As expected, the crop production with this moisture value showed successful results. We then determined the optimum moisture value, and created a simple and standardized irrigation control system using a watering control feedback mechanism based on the optimum moisture value. We also changed the Sandponics fertilizer to contain nitrate nitrogen, which is less toxic even if it accumulates. The combination of these two changes completely eliminated the cessation of growth.

We developed the new Sandponics system with the aim of simplifying irrigation (patent pending). **Figure 3** shows the differences in device configuration between the earlier and new Sandponics systems, and **Table 2** compares the functional differences.

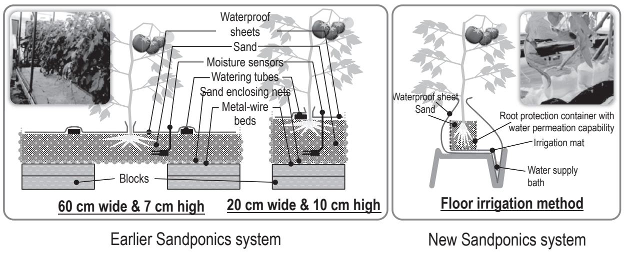

Fig. 3. Comparison of Device Configurations in the Earlier and New Sandponics Systems

Table 2. Comparison of Functions in the Earlier and New Sandponics Systems

	Earlier Sandponics system		New Sandponics system
	60 cm wide & 7 cm high	20 cm wide & 10 cm high	Floor irrigation method
Controllability	Average	Poor	Good
Automation capability	Average	Average	Good
Media quantity required to grow a single tomato plant	Poor (100%)	Average (47%)	Good (3%)
Water conservation capability	Poor (100%)	Average (47%)	Good (14%)
Facility costs	Poor (100%)	Average (51%)	Good (25%)
New technology features	● Feedback irrigation control based on moisture sensor measurement figures ● Moisture estimation based on past moisture change data ● Able to avoid drying out by visual display of sensor moisture reading		● Continuous moisture control by water level management ● Weight reduction and component configuration ● Able to avoid drying out by visual display of sensor moisture reading
Sugar content	7-9 (With controlled irrigation) 5-6 (Normal)	(Currently assessing)	7-9 (With controlled irrigation)
Estimated annual crop yields per 1,000 m^2	18 t (With controlled irrigation) 34 t (Normal)	(Currently assessing)	29 t (With controlled irrigation)

The new Sandponics system employs a floor irrigation method, in which watering is driven by the soil moisture tension of the medium. Watering pressure can be controlled seamlessly by changing the water level in the supply bath to the specifically required amount. This enables more precise irrigation than the earlier system (**Fig. 4**).

While the irrigation method adopted by the earlier Sandponics system was intermittent dripping, the floor irrigation method is continuous, making it easier to maintain moisture conditions. The soil moisture tension in sand is sufficiently powerful as the water absorption

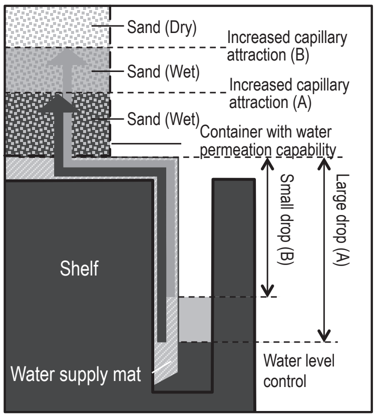

Fig. 4. Moisture Control by New Sandponics System

driver, and shows only small performance deterioration even after 25 years of cultivation. Sand is also suitable for this floor irrigation method. Furthermore, the floor irrigation method saves water as the evaporation from the medium surface is low. This results in a reduction of water consumption of 86% compared to the earlier Sandponics system.

Identification of the optimum moisture conditions and simplified irrigation, as well as change of the irrigation method made maintenance of the moisture conditions easier. This in turn eliminated the necessity to use a large quantity of sand as a buffer to maintain the moisture and reduced the sand required for cultivation. Even with our conventional irrigation method, stable crop yield could be achieved with half the quantity of sand. The sand quantity for the floor irrigation method was reduced by 97% compared to the quantity required when the optimum moisture value was unknown. Based on the reduced sand quantity, the equipment was redesigned and the estimated costs revised. The estimation resulted in a 49% cost reduction in the improved earlier system and 75% in the new system, both of which are lower than the standard Rockwool cultivation system.

To emphasize the Sandponics features, we introduced a minimum irrigation method, in which water is not supplied until the moisture in the sand is almost exhausted, with the aim of improving the taste through significant concentration of nutrition. The minimum irrigation is a known technique but the method to eliminate the concurrent risk of complete moisture exhaustion in the medium had not been established. As mentioned earlier, both the physical and chemical performance of the sand remain unchanged over the years as it is the medium with single-grained structure. This enables the prediction of water exhaustion timing and irrigation management, realizing the safe minimum irrigation. There are other methods to concentrate nutrition using additives such as salt, however, our method is an extended water conservation technique that maximizes the characteristics of the Sandponics system.

We have addressed and improved the challenges associated with the Sandponics system — the irrigation control and facility costs — through the methods described above, and further enhanced the Sandponics' main advantage, the excellent taste of its product.

4. Taste Assessment of Crops

The qualities most valued in the trade of agricultural product are taste, appearance, and supply stability. The crops with better taste are traded at higher prices. To claim that the Sandponics system produces crops with a better taste, their taste has to be assessed.

Sample tasting is the most basic assessment method, but the assessment results lack objective reliability, as the testers are influenced not only by the physiological effect but also by the psychological effect. Therefore the sample tasting cannot be used for quality assurance (**Fig. 5**).

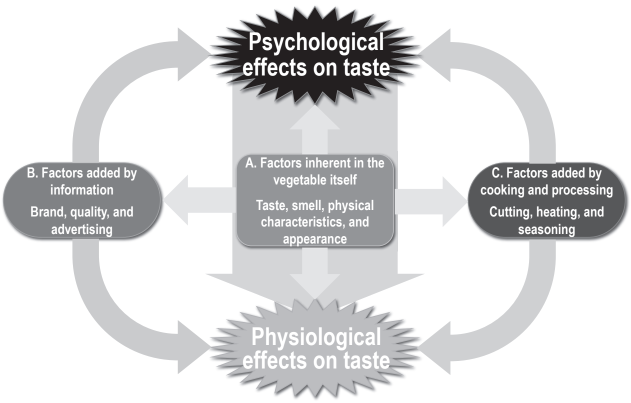

Fig. 5. Components of Taste

Component analysis, which is an objective method, is not suitable for tomatoes as it has the following characteristics:

(a) Complicated components: Trace quantities of components have a significant and complex contribution to a tomato's taste. It is difficult to analyze or imitate such combinations.

(b) Complicated structure: As the tastes and textures of the epicarp, mesocarp, endocarp, and parenchyma are different, assessment of each part is required. However, it is not possible to match them with the sample tasting results of a whole tomato fruit.

(c) Environmental factors: Uncontrollable external factors, such as transportation conditions and cooking, significantly influence the tomato's natural state.

However, sugar content (indicated by the Brix scale, the concentration of a dissolved solid in a liquid) has been identified as the component that shows a positive correlation with sample tasting assessment. High sugar content tomatoes are now being welcomed by domestic consumers. Measuring components that show a positive correlation with sample tasting assessment results is now used as a part of quality assurance.

Using the minimum irrigation method in the Sandponics system, it is possible to produce tomatoes with various sugar contents, from the level of the market standard to a premium level. The tomatoes with a high sugar content can be traded at a high price in the domestic market. Actually, a highly sweet tomato produced using the Sandponics system is rated by buyers at a much higher level than a standard tomato. This encouraged us to focus on highly sweet tomato production.

However, premium tomatoes with an extremely high sugar content are often associated with low yield due to the low weight of the fruits and their harder texture. For this reason, tomatoes of good size and relatively high sugar content and ranked between the premium and standard levels represent the most attractive product for both producers and consumers. The tomato that can offer both a good crop and excellent taste is indeed the very product that the Sandponics system can deliver.

The intra-company sample tasting session rated Sumitomo Electric's well-balanced tomato as "no skin left in the mouth, soft texture, good smell, and juicy." This was a better rating than Company A's tomatoes (representative product of high-lycopene tomatoes), which were rated as "good color and shape, but not sweet, and not juicy," and very close to the rating for Company B's tomatoes (representative product of high-sugar-content tomatoes), which were rated as "sweet, skin left in the mouth, hard texture, and small."

Our experiment proved that the Sandponics system is capable of producing novel tomatoes that can offer good size and sufficient sweetness rated as "tasty." It can be said that the Sandponics system, featured by its capability of improving the taste and texture, can cultivate agricultural products to respond to the demand for high quality product. The techniques developed for cultivation and taste quality assurance can be transferred to other crops with high market prices. It is also possible to develop a series of crops that share a unique standard under a single brand.

5. Conclusion

Sumitomo Electric's exclusive technology, the Sandponics system, had already been a competitive system due to its capability of producing crops with better taste and texture. This feature was further improved through a simplified irrigation method, and reduced equipment costs. An intra-company sample tasting session was held based on the revised method of quality assurance of taste and texture, and the session results demonstrated that the new Sandponics system achieved its original aim to produce a novel tomato that can offer good size and sufficient sweetness rated as "tasty."

We further plan to conduct large-scale field trials in order to improve the performance of our agricultural cultivation system and green house environment control. This trial will help us appropriately assess the profitability of agricultural production business using the Sandponics system. We can then assess the possibility of domestic and overseas expansion of our agricultural business model based on the Sandponics system.

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Contributors (The lead author is indicated by an asterisk (*).)

M. BABA*

• Ph. D.
New Business Frontier R&D Laboratories

N. IKEGUCHI

• Manager, New Business Frontier R&D Laboratories