Industry note of plant factory in Taiwan

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1 Introduction

The trend of population expansion is quite obvious in the world but not in Taiwan. It is estimated that the world population will be increased from 7 to 9.6 billion in less than 40 years. But Taiwan's population is shrinking. It is also estimated that 70% of the population will live in the city compared with the current 50% (Kozai, 2014). Taiwan has the same trend. It is clear that urban agriculture will rise and plant factory with artificial lighting (PFAL) can play an important role. As mentioned by Glaeser (2011), the development of the city should go up instead of going out occupying more lands. It is the same for the development of urban agriculture – PFAL is the answer. Many people in Taiwan share the same thought. We do believe that PFAL can make us richer, smarter, greener, healthier and happier.

There are 134 organisations involved in PFAL business in Taiwan in 2018. In 2012, just six years ago, there are 61 organisations. In 2016, there were 136, but in 2017, it dropped to 126. Half of those PFALs are small with daily production less than 100 plants and only one PFAL with daily production more than 10,000 plants, they are the largest PFAL with the daily harvest of 60,000 plants (2.5 tons of leafy greens). Over 90% of PFAL are located in one room within a floor of an office building or basement inside a building in some industrial parks of Big Taipei area (Taipei and New Taipei cities).

Some companies started to export and build 11 turn-key PFALs abroad, mainly in China. However, two out of those 11 were suspended due to some financial reasons. Three out of 11 built the PFALs in their own branch located in China.

2 PFAL Expo in Taiwan

To promote PFAL, related technical books were translated (Kozai, 2009, 2012; Takatsuji, 2007; Fang, 2011a, 2011c, 2012) and booklet and book (Fang, 2011b; Fang and Chen, 2014) for general public were published. Exhibition and conference were held by

Photonics Industry & Technology Development Association (PIDA) of Taiwan. PIDA held photonics festival in Taipei, Taiwan for a consecutive of 27 years. It is a NPO established by Taiwan Government to facilitate optoelectronic industry in Taiwan. Apart from an exhibition organiser, they also provide services such as industry research, consultation, promotion and communication in the industry and market. 2017 is the sixth year they combine PFAL topic within the festival. Another two NPOs, Taiwan plant factory industrial development association (TPFIDA, founded in 2011) and Chung-hwa plant factory association (CPFA founded in 2012), were major co-organisers. The number of booths related to PFAL increased from 36 to 108 from 2012 to 2014. Started from 2015, two organisations held exhibition separately, number of booths shrink. Some well established companies considered themselves have been well known in Taiwan, no need to attend expo for the increase of publicity, so they stop to participate.

In the PFAL booths, most of the companies demonstrate hardware used in PFAL. Several of them showed various spectra and controls of LED tubes and panels. Some showed locally developed or imported nutrient control system. Some booths are from Japan showing the PFAL turnkey capability and automatic fertigation equipment. Some booths are from Republic of Korea showing wireless control of LED light sources and LED chips. Also several local companies expressed their capability and experiences in turnkey projects. More than seven companies demonstrated the home appliance style plant growth desktop device and three showed growth bench to be used in the shop/restaurant/super market with or without controlled environmental capability. In 2011 to 2014s expo, one company shows the LED illuminated green wall with the air-cleaning capability, latterly, they work together with construction company to have their system embedded into some construction project and successfully exported the green wall and home appliance style plant grow device to Macao and Handan (a city in Hebei province of China). One company shows the aquaponics system, together with CHPFA, they were invited to Qatar to attend the agricultural exhibition. One company showed a variety of processed product with the PFAL grown vegetable ingredients. They participated the expo every year up to 2015. They were quite busy in reaching out and did not participated the expo in 2016 and 2017. This company is so far very successful, they setup a branch in Xiamen (China) in 2016 for the marketing of their processed product and planning to setup a PFAL for production, a research centre and a marketing office in Singapore in 2018.

3 PFAL Research

3.1 Cost comparison of vegetables produced from PFAL

Crops grown in PFAL can be separated into four types: ready to cook (RTC), ready to eat (RTE) and cook after wash (CAW), and eat after wash (EAW). Retail price of RTE lettuce and CAW Pak-Choi varies a lot, ranged from NT $500 to $2,000 and NT $200 to $300 per kg, respectively. There are some fundamental reasons for this dramatic difference on production cost. Mainly, high construction cost and equipment, especially the LED cost, lead to high depreciation and high labour cost and electricity cost lead to high operating cost. Advancement of technology has made cost of LED drop and

efficiency increase dramatically in recent years. At present, the electricity consumption can be as low as 7–10 kWh per kg compare with three years ago, range from 10 to 15 kWh per kg of leaf lettuce produced.

3.2 Quantitative evaluation of LEDs installed in PFAL

The arrangement of LEDs on a cultural bench might be vary due to different light sources used, different crops growth and other reasons. The manufacturers provide lumen per watt which is only suitable for indoor illumination and not appropriate for plant growth. In recent years, manufacturers started to provide light efficiency derived from PPF per watt of power consumed by the light source. PPF is in the number of micro-mole per second and watt equals joule per second, thus PPF/W is in the unit of micro-mole per Joule. This is a good indicator for plant growth; however, it does not represent how well the light installed on the cultural bench. A quantitative measure using micro-mole per Joule as the unit was defined as quantum-energy ratio (QE ratio), which is average photons (PAR range) measured on cultural bed (PPFD) times area of the cultural bed (A) divided by total watt (W) of lamps installed. By definition, this QE ratio is not the same with the light efficiency (PPF/W) although both are in the same unit. At present, the PPF/W is less than 2.5. But the QE ratio can be as high as 4.2 due to the usage of reflectors, longer in length of LED tubes and usage of white growth panel.

3.3 WSN in PFAL

Wireless sensor network (WSN) is used to evaluate the uniformity of air temperature, humidity, and light intensity horizontally in a layer and vertically within layers of a PFAL (Chang et al., 2011; Juo et al., 2012). Each wireless sensor module is equipped with temperature, relative humidity and light sensors, hanging on top of crops in each layer of cultural benches for the verification of the uniformity of distributions of light and air. The temperature distribution was found to be related to the distribution of the fresh weight harvested. It means that increase of uniformity of temperature takes place to reduce the variation on final fresh weight. A smart fan system is developed for such purpose (Lee et al., 2013). The rapid development of IOT technology has made PFAL equipped with more intelligent. Advancement of ZigBee and Bluetooth technology has made related hardware use much less electricity compare with same technology three years ago. Wi-Fi may not be the best technology anymore for the indoor environment such as PFAL.

3.4 Ion-selective sensors for nutrient detection

Traditional ion-selective sensors are quite expensive and are short in usable lifespan. New ion-selective sensors for the detection of macro-elements in nutrient solution are developed. After five years of research, seven screen-printed ion-selective electrodes (ISEs) for six macro-elements were developed (for nitrogen, there are two electrodes including ammonium and nitrate detection). However, they are not commercially available now.

3.5 Non-destructive plant growth measurement system

A measurement system with cameras attached to a sliding rail on each layer of cultural bench accompanying with weighing devices for each plant was developed for continuous and automatic plant growth measurement. The system is capable of taking images at preset time interval and stitches all images across the cultural bed to form a panoramic image of the cultural bed using a computer with image processing capability. In the recording process, the cameras move across the whole cultural bed in order to acquire images. Temperature and humidity sensors are also integrated with the imaging system to acquire spatial-temporal environmental information during the plant growth period. The image processing algorithms, that calculated geometric features such as the projected leaf area, plant height, volume and diameters are developed and incorporated into the automated measurement system (Chen et al., 2016). The accompanying automatic weighing system using load cells was also developed to record the fresh weight of individual plants throughout entire growth period. The weighing system can also be applied to measure plant growth as an independent system. For the weighing system, the load cell signals are calibrated, acquired and displayed in real time. The data are analysed in correspondence with the plant geometric features obtained from the imaging system allowing derivation of plant growth model under various controlled environmental conditions. This plant growth measurement system provides a non-destructive and real-time processing approach over the traditional measuring methods. Furthermore, the automation feature of the system enables the system to gather a large number of plant measurements easily. Hence, the system is an efficient and practicable tool to enhance the growing environment parameters tuning and optimisation in a plant factory environment.

3.6 LED tubes with adjustable spectrum and intensity

It is well known that for seedling production, vegetable plants prefer more blue than red light. But for vegetative grow after transplanting, plants prefer more red than blue. One might mistakenly thought that green leaf reflects green lights, thus they do not need green light. Based on recent researches, it is quite sure that wide spectrum is better than narrow spectrum with just R (600–700 nm) and B (400–500 nm) only. However, plants do not need too much green is also well known. For regular indoor illumination, the cool white, warm white and day light LED tubes provide too much (more than 45% of PAR) green portion of light (500–600 nm). This kind of light sources maybe the cheapest but not the best light source for plants.

We have developed 4 types of LED lamps, R/B, R/W, R/W/B, R/FR adjustable, with capabilities of adjusting spectrum on-site without replacing lamps and adjusting intensity on-site without adjusting the distance from lamps to plants or change the number of lamps installed. For R/B adjustable, there is 21 spectra can be chosen by selecting the desired R/B value in the wired controller or with the wireless module by App using smart phone. For R/W/B, R/W and R/FR adjustable, there are 19 spectra available. The powers of all these lamps can also adjustable range from 5 W to 25 W per tube to provide different intensity. They are now commercially available from local company of Taiwan.

3.7 UV and FR for phytochemical production and morphogenesis research

UV promotes the phytochemical production in plants. UVA ranges from 315 to 400 nm and UVB range from 280 to 315 nm. UVC should not be used for plant production but UVB and UVA can be used normally related to phytochemical production in plants. UVB is much energy intensive compare with UVA, thus need to be used carefully. The usage should be calculated similar to the concept of DLI (daily light integral, PPFD times hours per day illuminated), dosage of UV equals intensity multiply by duration normally minutes for UVB and hours for UVA. Our focus of using UV is on some medicinal plants and red leaf lettuce production.

Research on FR in controlled environment is recent focus worldwide. Some research focusing on EOD effect and some focusing on flower induction for ornamental plants. We have the keen eye on inhibit flowering of spinach of local variety, which is LD plant. It will turn head sprouting if duration of light is longer than 12 hours. To prevent flowering, traditional way of production using artificial light in CA is normally provide with 11 hours of light. In a plant factory, we would like to provide longer duration of light in order to gain more fresh weight for market. Thus, a research using FR to inhibit flowering was conducted. The result is quite promising. We are able to provide 14 hours of light with less than 10% of flowering. The fresh weight can be increased from 60 grams per plant at 11 hours using CW LED only up to 160 grams per plant at 14 hours of CW LED and FR.

3.8 Low potassium lettuce production for ESRD patients

ESRD stands for end stage renal disease. Patients at ESRD required hemodialysis as well as need to be very careful in potassium intake. One of the major sources for an adult to intake potassium is from vegetables (300 ppm or more for lettuce). Potassium (K) is one of three macro-elements (N, P, K) that the plant need. With less amount of potassium, the plant cannot grow well. There is a Japanese company and one Taiwanese company capable of producing low potassium (less than 100 ppm) Lettuce with the sacrifice of fresh weight (less than 60 grams per plant). However, their method of production is to replace potassium with sodium in the nutrient solution. Eventually, the product will have low K but high Na. This is also no good for patients with kidney disease and patients with high blood pressure, with heart disease as well.

Some companies in Taiwan have ‘healthy salt’ as their slogan to promote their product, it says only 50% salt compare with other brand. The secret they did not emphasise is that they use KCl to replace NaCl. The idea is exactly the same with the previously mentioned PFAL in Japan and Taiwan, producing low potassium lettuce using Na to replace K in the solution.

Without using Na to replace K, we used NH_4 to replace K in the solution, capable of producing not only low potassium, but also low sodium and low nitrate lettuce without sacrifice too much of the fresh weight (Fang and Chung, 2017).

4 Business models of PFAL in Taiwan

PFAL is an eye-catching point for it is new to general public and features of PFAL attract environmental concerned and health concerned consumers. However, without proper business model, it is still highly possible a cash-trap if not considered thoughtfully. For the hardware installation we need engineering success; for the management of production, shipping and handling, we need skilful workers in order to have operational success; for the marketing and banking, we need to have financial success. In order to have financial success, the manager should ask himself/herself: how well he/she can sell their products at what price; how long their products can lasts without loosing their value; what are the risks in production and in marketing?

There are various types of business models being tested in the market of Taiwan (Fang, 2014). The product can be the plant itself such as in the forms of a whole plant, loose leaf or baby leaf. The way to present the product is very important, such as the way of packaging, a sealed soft plastic bag, a soft plastic bag with tiny holes or a sealed hard plastic box. Different packaging method related to different story you expressed to the customers, involved with different cost of course. It is a product no need to wash before eat or just similar to products grown in greenhouse? It is a locally made not imported is also important issue to emphasise. Some also provide with salad dressing, the tastefulness of the dressing is also of great importance. One common thing is that the packaging bags and boxes are normally well designed to make it much more pleasant in the appearance compare with traditional agricultural products.

The sale channels can be membership-based, through the website, within the company or to the local community. It is important that one should limit their amount of sale through 3rd party. It is quite clear that sell the products through supermarket chain store (owned by others) can only be a temperate conduct, the shelf-charge is normally too high. That is to say, for PFAL product, business to consumer (B2C) is much favourable than business to business (B2B).

If the company cannot sell all their products, other product-line is considered. One company in Taiwan developed more than ten kinds of processed products with vegetable ingredients such as ice-cream, egg roll, bread, noodles, face mask, skincare soap, etc. It can also be served as nutritional additive in various forms such as juice, powder and tablets. Different kinds of vege-additives have different prices in same product. For example, noodles with butter-lettuce and with ice-plant cost differently.

A construction company combined the PFAL concept in their community construction plan. Each family will have a home appliance style device to grow vegetables at home and the community will have a service division providing seeds, seedlings, and stock nutrient solutions, etc. to community residents. A green life style is proposed.

A shop has PFAL in the back or in one side and have restaurant or stands selling organic products in front are popular business models in Taiwan. Such shops are normally chain-stores and located in various corners within cities.

Several companies focus on the development and sale of the home appliance style plant production units and indoor green walls for home use. One company produces aquaponics units for hobby growers and home owners.

Some companies capable of constructing PFAL for others, most of them have a demo-site for potential customers to take a look for further consideration. Some successful company will have a demo-site with a more convincing scale normally at daily

production of no less than 100 plants and need to be operated smoothly for more than several months. With an established sale channel is most welcomed. Unfortunately, few companies reach these requirements that made them less convincing.

Many PFAL related hardware providers such as LED providers, clean room constructors, air conditioning system providers, hydroponics system providers, power supply providers and thermally insulated material providers, these companies started to build PFAL demo room and started to learn how to grow plants. To become a PFAL turn-key provider is their common goal.

In short, there are several distinct business models under practice in Taiwan.

1 PFAL produces leafy greens for their own usage. For example, restaurant owners and corporation with more than 1,000 employee.

2 PFAL produces leafy greens for online customers and members. Some companies are quite flexible, they even exchanged membership with other health related organisation such as yoga club.

3 PFAL produces leafy greens and processed products with vege-additives.

4 PFAL produces leafy greens is an eye catching point but with other profit making means such as construction, chain-store selling organic dry foods.

5 Home appliance style PFAL module providers with demo room.

6 Home appliance style PFAL module providers with alliance in construction industry.

7 PFAL related hardware providers built PFAL demo rooms to sell their products and plan to become turn-key provider.

8 PFAL turn-key builders and consultants with or without PFAL demo room.

As mentioned above, the PFALs in Taiwan although small in scale, but are flexible and dare to try various business models. At present, some looks promising, some has been failed. Even the same business model, still some win some lose as same as other emerging industry.

5 Conclusions

The PFAL is booming in Taiwan. Without financial and policy support from the government, private companies involved in this new industry with great interest. The PFAL related NPO organisations are established, enabling the horizontal and vertical connection and integration of companies.

At present, there is no private agricultural organisation involved in PFAL in Taiwan. Several farmers' associations were considered to convert their unused warehouse to PFAL, but finally dropped the idea. High initial cost is the first concern, difficult to find quality workers and manager to run the PFAL is another concern. It is quite true that at least at present, number of qualified managers and quality workers are not enough in the PFAL industry of Taiwan. Besides academic training in undergraduate and graduate schools of Taiwan, our team offers 30 hours and 18 hours workshops twice per year and once per season, respectively. Up to now, more than 900 people have been trained, but less than 10% of them really get involved in the business afterward and less than 5% with

agricultural background. To train qualified managers and quality workers for PFAL industry is an issue need to be taken care to enabling the worldwide business opportunities.

Many companies got involved with a keen eye looking at the business opportunities of the turnkey projects. However, some failed to proof that their system can grow quality plants efficiently. It is also sad to find that some companies considered PFAL an opportunity to make quick money which lead to law suits and public confusion. Up to now, all the so-called international turnkey projects, around 15 PFALs built by Taiwan PFAL companies, mostly in China and one in S.E.A.

Some consumers question about using artificial lights and hydroponics. Not nature, all chemicals were frequent challenged complains four years ago. Public awareness, food safety problems, environmental problems and frequent media exposures of PFAL help consumers to learn about the technologies, appreciate the technologies and willing to pay extra money to buy products from PFAL. Nevertheless, to bring down the cost, increase the value, increase the suitable varieties to be grown in PFAL are tasks to be done. PFAL will co-exists with organic agriculture and traditional agriculture. With no doubt, PFAL can also play key role in urban agriculture, in smart/intelligent city.

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